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ROYAL OBSERVATORY, GREENWICH.

OBSERVATIONS OF
COLOUR TEMPERATURES
OF STARS

1926—1932.

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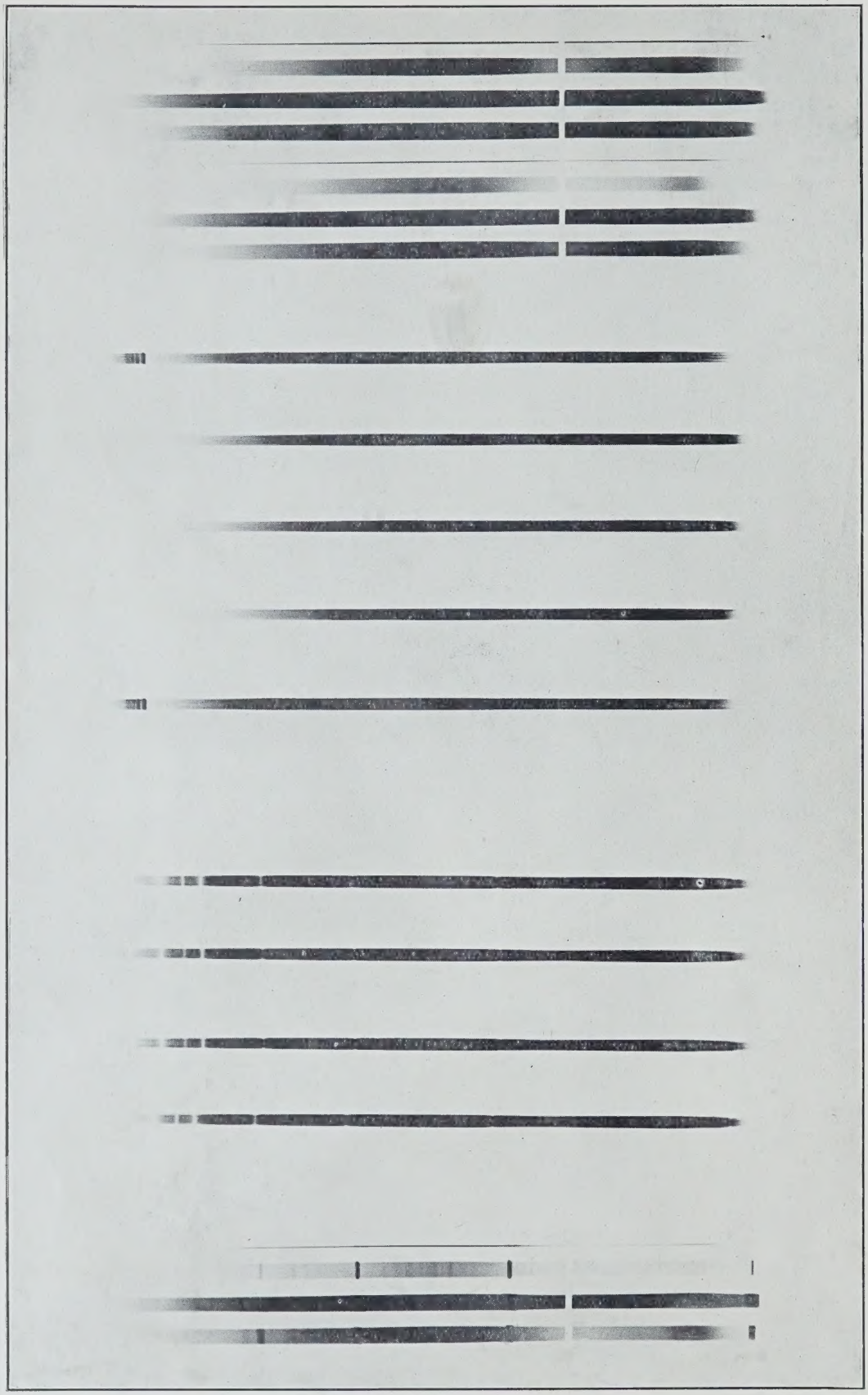

a, Scale of Light Intensity. Full aperture.
b, ,, ,, ,, ,, Half aperture.
c, *g*, Carbon arc for deducing wave-lengths in the Acetylene spectrum.
d, *e*, *f*, Acetylene, screened with blue filter.
h, α Ophiuchi, zenith distance 53°.
i, *j*, γ Ursæ Minoris, ,, ,, 21°.
k, δ Leonis, ,, ,, 55°.
l, Hydrogen for deducing wave-lengths in *a* and *b*.

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OBSERVATIONS OF

COLOUR TEMPERATURES OF STARS

MADE AT THE ROYAL OBSERVATORY, GREENWICH
IN THE YEARS 1926-1932, UNDER
THE DIRECTION OF

SIR FRANK DYSON, K.B.E., F.R.S.
ASTRONOMER ROYAL

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ROYAL OBSERVATORY, GREENWICH.

OBSERVATIONS OF COLOUR TEMPERATURE OF STARS, 1926-1932.

ERRATA.

Page 22, *line* 4. The formula should read:

$$-\frac{1}{\lambda}\cdot\Delta\phi + k = \Delta m_\lambda \times 0{\cdot}921$$

Page 25, *line* 7. The formula should read:

$$\Delta\phi_1 = -\frac{d}{d(1/\lambda)}\cdot\Delta m_\lambda \times 0{\cdot}921$$

Page 25, *line* 9. The formula should read:

$$A = +\frac{d}{d(1/\lambda)}A_\lambda \times 0{\cdot}921$$

NOTE.—The omission of the factor 0·921 in the formulæ as printed was an error made in the preparation of the copy for press. The factor was correctly included in the computations and the published numerical results are unaffected.

F. W. DYSON,
Astronomer Royal.

1932, *September* 27.

INTRODUCTION.

1. *Application of Planck's formula.*

This volume presents the results of colour temperature observations of stars extending over the period 1926 January to 1932 March.

It is an observational fact that the distribution of the light in the continuous spectrum* of a star is that of a " grey body " over a considerable range of wave-length.†

" Grey body " radiators are defined by the property that the light emitted by them is proportional, as far as the relative distribution throughout the spectrum is concerned, to the light emitted by " black bodies."

Consider firstly the case of " black body " radiation (the radiation emitted from a small aperture in a temperature enclosure). Let I_λ denote the amount of energy emitted per unit wave-length per unit area per second at wave-length λ. Then I_λ will be given by Planck's formula viz :—

$$I_\lambda = 2\pi hc^2\lambda^{-5} \Big/ \left(e^{hc/R\lambda T} - 1\right)$$

where c is the velocity of light and $= 3{\cdot}00 \times 10^{10}$ in c.g.s. measure.

h is Planck's constant and $= 6{\cdot}55 \times 10^{-27}$.

R is Boltzmann's constant and $= 1{\cdot}372 \times 10^{-16}$.

and T is the temperature of the enclosure on the absolute scale.

In the class of radiators called grey bodies, the observed relative distribution of energy throughout the spectrum is that of *some* black body, although the absolute amounts of energy radiated per unit wave-length per unit area per second are not calculable from Planck's formula. Examples of " grey bodies " are electric filament lamps, and the acetylene flame. When the light emitted by a " grey body " is being observed we may denote by I_λ the amount of light per unit wave-length at wave-length λ incident on the receiving apparatus. The ratios of the I_λ will be derived from the formula—

$$I_\lambda = c_1\lambda^{-5} \Big/ \left(e^{c_2/\lambda T} - 1\right)$$

where $c_2 = hc/R = 1{\cdot}432$ cms. degrees,

c_1 is independent of λ,

and T is *some* temperature.

The temperature T is called the colour temperature of the observed radiation. It is essentially a measure of colour and it must be emphasized that in expressing the results of colour measurements as *temperatures* we are merely following a convenient and well recognised convention. The relation between the colour temperature of a star and, say, the mean temperature of its reversing layer, must depend on the radiative structure of the boundary layers and does not concern the observer as such.

* i.e. when measurements are taken *between* the absorption lines and bands.

† See p. 34.

It is clear that if at wave-length λ the quantity $\frac{d}{d\lambda} \log_e I_\lambda$ be observed the colour temperature T can be deduced by an application of the above formula. In practice, however, it is convenient to derive T from measures of the quantity

$$\frac{d}{d(1/\lambda)} \cdot \log_e I_\lambda$$

for reasons which will appear presently. Furthermore in spectrophotometric determinations this quantity is determined by measuring the difference between it and the corresponding quantity for a comparison source of known colour temperature. The quantity to be measured is thus :—

$$\frac{d}{d(1/\lambda)} \cdot \log_e (I_\lambda/I'_\lambda)$$

where I'_λ refers to the comparison spectrum.

A convenience of this procedure may be noticed at this point. All methods must aim at measuring the light flux on a portion of the spectrum whose breadth in linear dimensions is some constant, *dx* say. *dx* may be the breadth of an analysing slit or the breadth of the real image of an incandescent filament in a microphotometer (see below). For grating dispersion *dx* will represent the same $d\lambda$ for all wave-lengths, but for prismatic dispersions this is not the case. Now I_λ has been defined as the light flux *per unit wave-length* at wave-length λ and if we were trying to measure I_λ directly, we should have to apply troublesome corrections to measures of prismatic spectra. But as we are only going to be concerned with the ratios I_λ/I'_λ, it is not necessary to reduce the breadth of the photometer slit or its equivalent to angström units, provided the same breadth be used throughout the measurement of both the spectra.

From the formula for I_λ it follows that :—

$$\log_e (I_\lambda/I'_\lambda) = \log_e \left(e^{c_2/\lambda T'} - 1\right) - \log_e \left(e^{c_2/\lambda T} - 1\right)$$

whence by differentiation

$$\frac{d}{d(1/\lambda)} \cdot \log_e (I_\lambda/I'_\lambda) = \phi' - \phi = \Delta\phi \text{ say.}$$

where

$$\phi = \frac{c_2}{T} \Big/ \left(1 - e^{-c_2/\lambda T}\right)$$

and ϕ' is the same function of T'.

The convenience of this relation arises from the fact that in practice the variation of $\Delta\phi$ with wave-length over the spectral range used is small and so the plot of $\log_e (I_\lambda/I'_\lambda)$ against $1/\lambda$ is very nearly linear. Consequently $\Delta\phi$ can be obtained by taking a series of measures of $\log_e (I_\lambda/I'_\lambda)$ over a considerable range of wave-length. These measures can be plotted against $1/\lambda$ and a straight line fitted to the plotted points. The slope of this line gives $\Delta\phi$ for $\lambda = \lambda_m$ where λ_m is the mean wave-length of the spectral range used. In the case of the measures discussed in this volume, the range of wave-length is such that the mean wave-length λ_m can be taken as 5000 angströms.

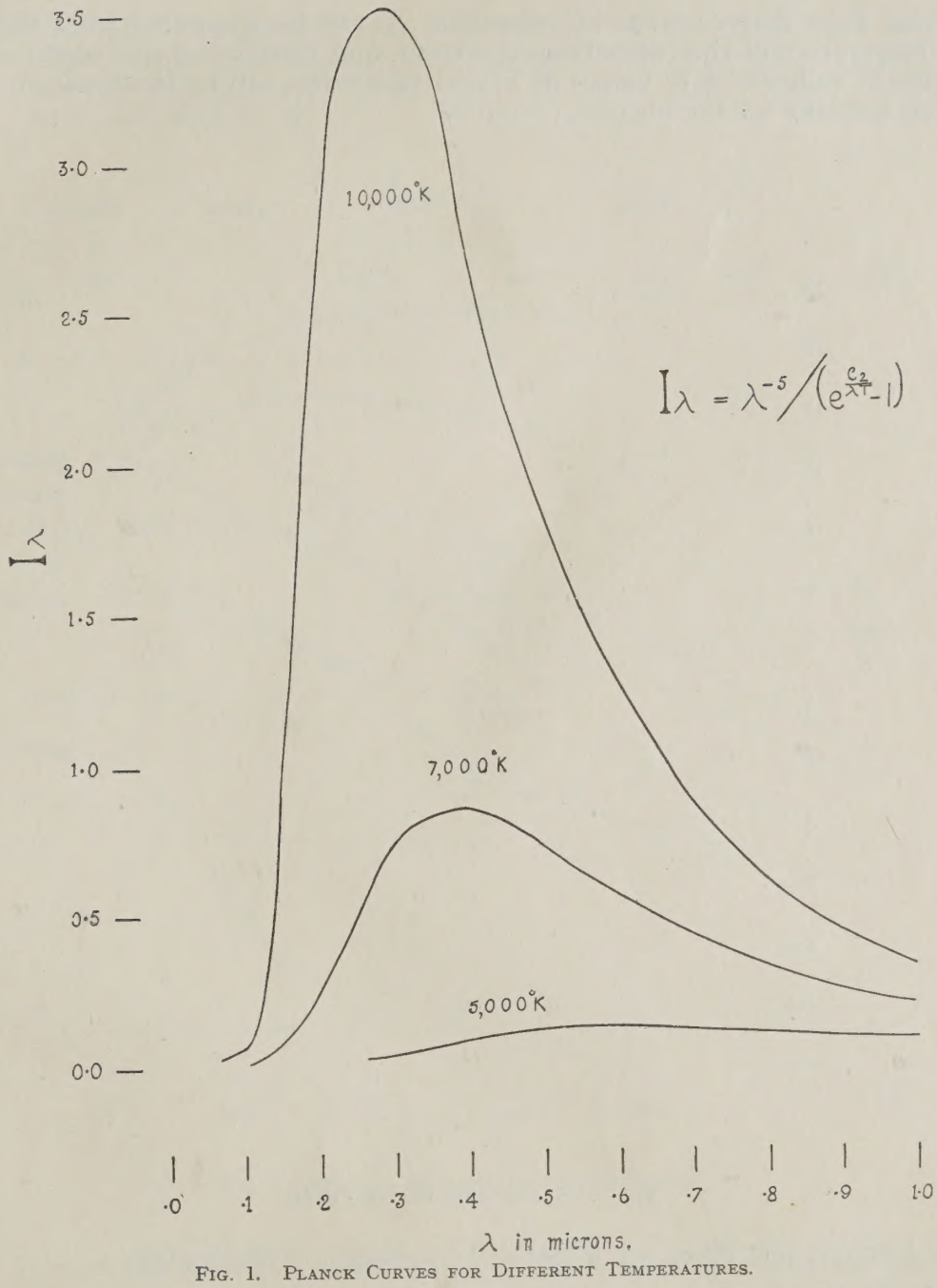

FIG. 1. PLANCK CURVES FOR DIFFERENT TEMPERATURES.

In applications of Planck's formula it is usual to use the micron ($= 10^{-4}$cms.) as the unit of length. We shall then have

$$c_2 = 14320, \quad \lambda_m = 0{\cdot}5, \quad \text{and } \phi = \frac{c_2}{T} \Big/ \left(1 - e^{-2c_2/T}\right).$$

$\Delta\phi$ having been derived from the measures, ϕ' can be computed from the known colour temperature of the comparison spectrum, and then ϕ and so T deduced. The conversion of values of ϕ to values of T, and vice versa, can be facilitated by a table computed specially for the purpose (see p. 63).

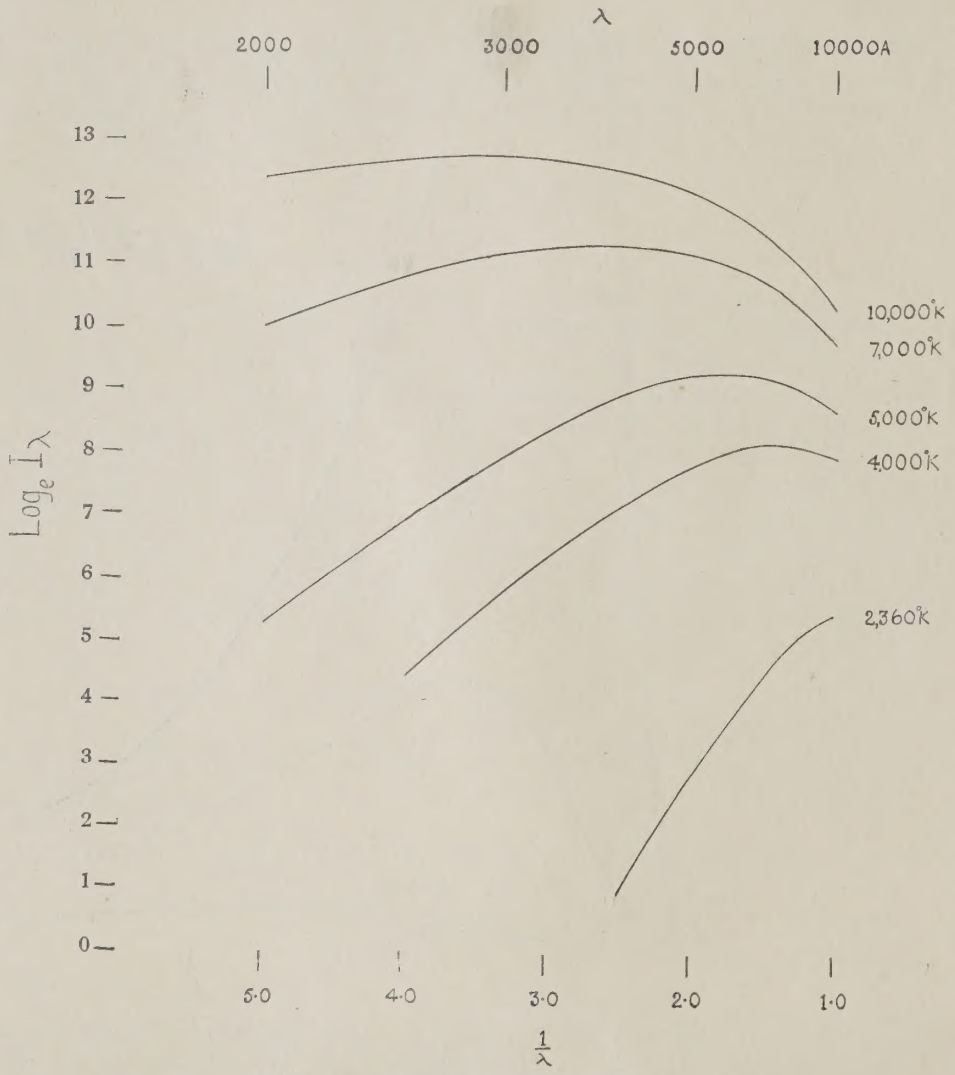

FIG. 2. LOGARITHMIC PLANCK CURVES.

The formulæ just given are illustrated by diagrams which give

(1) Planck curves for I_λ plotted against λ.
Each of these curves involves an unknown scale since c_1 is unknown.

(2) The logarithmic curves for $log_e I_\lambda$ plotted against $1/\lambda$.
Each of these involves an unknown zero.

(3) The logarithmic curves when differenced from the curve for $T = 2360°$ K which has been taken as the temperature of the comparison source. These curves are very nearly straight lines and their slopes depend mainly on T and only slightly on λ.

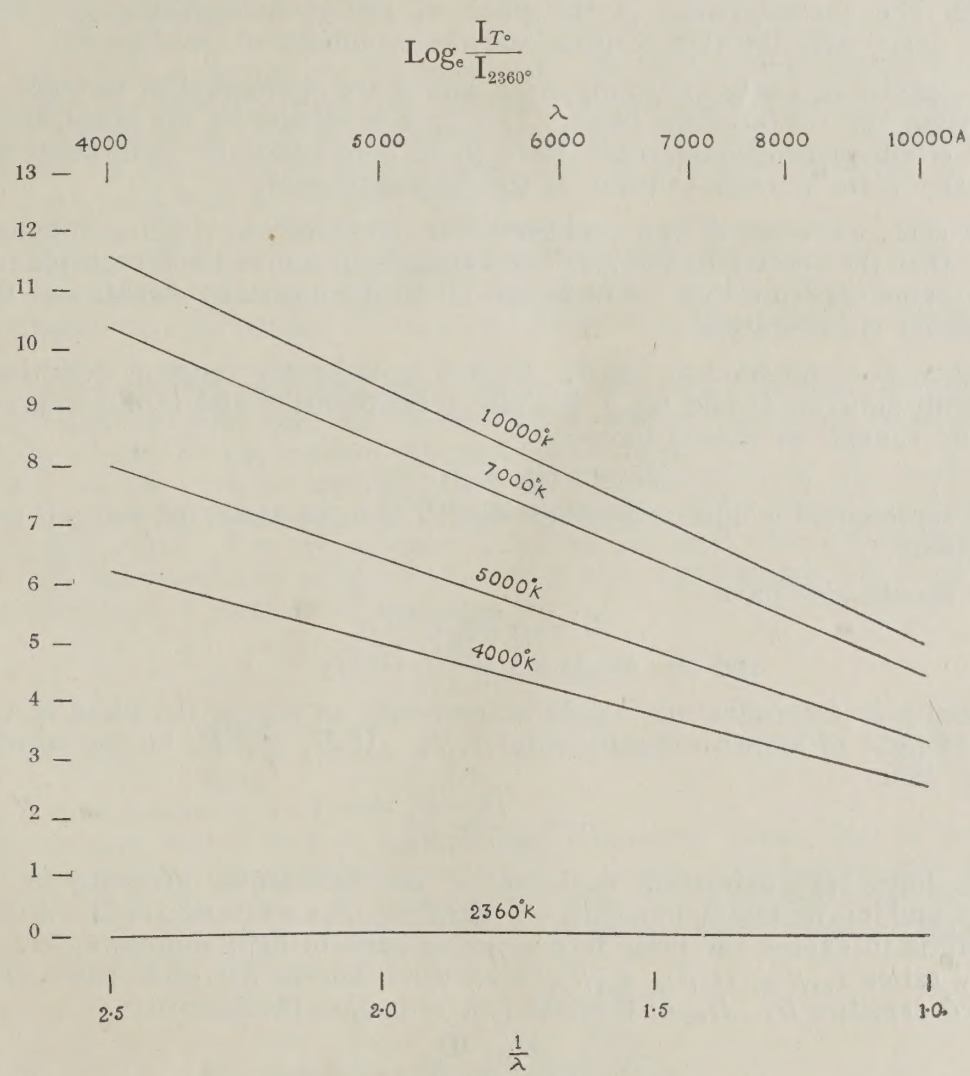

FIG. 3. REDUCED LOGARITHMIC PLANCK CURVES.

2. *Photographic Theory.*—From the foregoing it is evident that the problem of observing the colour temperature of a star reduces to the photometric problem of measuring the quantities $log_e (I_\lambda/I'_\lambda)$ for various values of λ.

The method used in the observations set forth in this volume is a photographic one. The spectra of the stars and the comparison source are photographed and the

optical densities of the reduced silver* at the requisite points on the negatives are measured with a suitable microphotometer. The density thus measured will depend on

(1) The light flux as affected by the optical train used,

and (2) The characteristics of the plate at the wave-lengths used. These will vary with the type of plate and the conditions of development.

The spectra of a star and comparison source are photographed through the same optical train and on the same plate. This process eliminates the absorptions of the train. Certain plate characteristics have to be determined by calibration exposures on the same plate, referred to below as the scale exposures.

For each wave-length the problem is to measure $log_e (I/I')$. Suppose for the moment that the spectra of the star and comparison source have been photographed with the same exposure time. Let D and D' be the measured densities at the wave-length under consideration.

D will then be a function of $log_e I$. Over a considerable range of densities a linear relationship between D and $log_e I$ is a fair approximation and if this approximation were good enough we should have :—

$$D = \gamma \, log_e (I/I_o)$$

where I_o represents the unit in terms of which I is to be measured and γ is a constant for the plate.

We should also have

$$D' = \gamma \, log_e (I'/I_o)$$

$$\text{and so} \quad log_e (I/I') = (D-D')/\gamma.$$

In order to determine γ it would be necessary to expose the plate to two other sources of light of known intensity ratio I_1/I_2. If D_1 and D_2 be the corresponding densities, then

$$\gamma = \frac{D_1-D_2}{log_e (I_1/I_2)}.$$

This linear approximation is, however, not sufficiently accurate for practical purposes, and it is necessary to regard $\gamma = dD/d \, log_e I$ as a function of D. A convenient procedure is to expose the plate to a series of pairs of light sources a, b, c, etc., the intensity ratios I_{a1}/I_{a2}, I_{b1}/I_{b2}, I_{c1}/I_{c2}, etc., being known for each pair. From the measured densities D_{a1}, D_{a2} of the first pair of images the quantity

$$\gamma_a = \frac{D_{a1}-D_{a2}}{log_e (I_{a1}/I_{a2})}$$

is formed and similarly for γ_b, γ_c, etc. The quantities γ_a, etc., are then plotted against the arguments $\frac{1}{2} (D_{a1} + D_{a2})$, etc. The value of γ for argument $\frac{1}{2} (D + D')$ is then read off. This is inserted in the equation

$$log_e (I/I') = (D - D')/\gamma$$

from which $log_e (I/I')$ is calculated.

---

* By optical density is meant the quantity $log_{10} (1/\tau)$ where τ is the transmission when a beam of light is passed through the image ; i.e. τ is the ratio of the transmitted to the incident light.

The whole of this procedure is repeated at various wave-lengths. From the values of $log_e\,(I_\lambda/I'_\lambda)$ so obtained, the quantity

$$\Delta\phi = \frac{d}{d(1/\lambda)} \cdot log_e\,(I_\lambda/I'_\lambda) \text{ is derived.}$$

The series of pairs of exposures *a*, *b*, *c*, etc., comprise the *photometric scale* which has to be imprinted on each plate.

3. *The effect of varying the exposure time.*—In the previous section it has been assumed that the exposure times for the star, the comparison source, and the pairs of spectra constituting the photometric scale are the same. In practice such a restriction is exceedingly inconvenient and it becomes necessary to enquire whether departures from it will lead to error.

The problem may be put in the following form :—The spectra of the star, comparison source, and scales are photographed with different exposure times, but the densities are reduced by the method of the previous section, that is just as if the exposure times were all equal. What error, if any, is produced in the resulting value of $\Delta\phi$?

If t denote the exposure time then the density D must be a function of I and t. It is clear that the above question can only be answered if we know something about the way in which the time enters into the relationship.

It was shown by Schwarzschild that an approximation to the observed facts could be obtained by assuming that D was a function of $I\,t^p$ where p is constant for any particular plate. For the moment it will be assumed that p is independent of I and t, but the possibility of a variation of p with wave-length will be considered.

We then have a relation of the form

$$D = f(E)$$

where $E = log_e\,I + p\,log_e\,t$

write $\dfrac{\partial D}{\partial log_e\,I} = \gamma$

then $\gamma = f'(E)$

so that γ is a function of D only.

Suppose now that a scale is printed on the plate as before, that is the plate is exposed to a series of pairs of light sources *a*, *b*, *c*, etc., with known intensity ratios I_{a1}/I_{a2}, I_{b1}/I_{b2}, I_{c1}/I_{c2}, etc. It is necessary that the exposure time for the two members of each pair should be equal, but the exposures for the different pairs may be different, and will be denoted by t_a, t_b, t_c, etc.

Then $E_{a1} = log_e\,I_{a1} + p\,log_e\,t_a$

and $E_{a2} = log_e\,I_{a2} + p\,log_e\,t_a$

so that $E_{a1} - E_{a2} = log_e\,(I_{a1}/I_{a2})$

If D_{a1} and D_{a2} be the corresponding densities, then the value of γ corresponding to $D = \frac{1}{2}\,(D_{a1} + D_{a2})$ is to a good approximation (provided D_{a1} and D_{a2} are not too widely different*)

$$\gamma = \frac{D_{a1} - D_{a2}}{E_{a1} - E_{a2}} = \frac{D_{a1} - D_{a2}}{log_e\,(I_{a1}/I_{a2})}$$

* Over a considerable range of density the relationship between D and E is nearly linear, and a considerable margin is allowable. Light ratios of 2 : 1 can be used in practice.

It is to be noticed that t_a does not enter into this result, which is identical with that obtained in the previous section for the case of a standard exposure time. γ is thus obtained as a function of D in the same way as before, and the exposure times t_a, t_b, etc., are immaterial.

Suppose now I_1 and I_2 be the light fluxes from the star and comparison sources, let t_1 and t_2 be the exposure times, D_1 and D_2 the densities, and E_1 and E_2 the corresponding values of E. Provided D_1 and D_2 be not too widely different* we have

$$D_1 - D_2 = \gamma (E_1 - E_2)$$

where the value of γ to be taken is that corresponding to density $D = \frac{1}{2}(D_1 + D_2)$.

This gives :—

$$D_1 - D_2 = \gamma \log_e (I_1/I_2) + p\gamma \log_e (t_1/t_2)$$

$$\text{and so,} \quad \log_e (I_1/I_2) = \frac{D_1 - D_2}{\gamma} - p \log_e (t_1/t_2)$$

$$\text{whence} \quad \frac{d}{d(1/\lambda)} \cdot \log_e (I_1/I_2) = \frac{d}{d(1/\lambda)} \cdot \frac{D_1 - D_2}{\gamma} - \frac{dp}{d(1/\lambda)} \cdot \log_e (t_1/t_2)$$

On comparing this result with the formulæ of section 2 it is seen that the error introduced into $\Delta\phi$ by reducing the measures of density just as if the exposure times were equal is

$$- \frac{dp}{d(1/\lambda)} \cdot \log_e (t_1/t_2)$$

It follows that the error will vanish if p is independent of wave-length.

The existence or otherwise of an error of this kind can be tested by a comparison of a source of light against itself. Two exposures are made on the source with different exposure times, a suitable method being employed for the purpose of reducing the light flux in the case of the longer exposure. The two spectra are then measured and reduced just as if they had been the spectra of star and comparison source. If there is no error dependent on exposure time the resulting value of $\Delta\phi$ should be zero. It has been found that such indeed is the case, and the details will be given in a subsequent section.

But it would be dangerous to infer that no appreciable error, arising from variations in exposure times, is introduced when large colour differences are being measured. The Schwarzschild assumption that the density is a function of It^p is known to be a good approximation but it cannot be regarded as more than that. In fact it is known that p is not constant but varies from about 0·7 for an exposure to feeble light to values exceeding 1·0 for intense light fluxes.† This means that p is a function of I, and this circumstance leads to consequences which cannot be disregarded.

We now have :—

$$D = f(E)$$

$$\text{where} \quad E = \log_e I + p \log_e t$$

$$\text{and} \quad \gamma = \frac{\partial D}{\partial \log_e I} = f'(E) \left[1 + \log_e t \cdot \frac{dp}{d \log_e I}\right]$$

This may be written :—

$$\gamma = \gamma_0 (1 + \varepsilon \log_e t)$$

* See previous footnote.

† See F. E. Ross, *The Physics of the Developed Photographic Image*, p. 61 *et seq.*

Now $\gamma_o = f'(E)$ and is a function of D only. Also $\varepsilon = \frac{dp}{d \log_e I}$ and is positive. Hence for a given D, γ should increase with the exposure time t. This effect has been shown to exist qualitatively by actual experiment.

It follows that when constancy of exposure time is not maintained over a plate, error will be introduced by treating γ as a function of D alone. It should be observed that experiments of the kind mentioned above, in which the values of $\Delta\phi$ are determined for comparisons between a source of light and itself, do not provide any information as to the possibilities of error when large values of $\Delta\phi$ are being measured. The experiments in question do indeed negative any suggestion of significant error for small values of $\Delta\phi$, but they leave open the possibility of percentage errors, such as may be introduced by a percentage error in the values of γ, which may affect the measures of large $\Delta\phi$ to an appreciable extent.

The conclusion is that when small differences of colour temperature are being measured a certain amount of latitude is permissible with the exposure times, but even then care should be taken that the exposure time for the scales should not be very different from the average time for the other exposures. In addition to this, experience has suggested a further precaution, viz :—that the optical train should be so adjusted that the densities of the spectra at the ends of the spectral range used are not too widely different.*

But when large differences of colour temperature are being measured, the same exposure time should be maintained for the whole plate including the scale exposures. This restriction would be very awkward when applied to plates taken at the telescope, but the colour differences can always be reduced to small quantities by the use of colour filters (e.g. the insertion of a suitable blue filter for the exposure on the redder light source). This procedure requires that the absorptions of the filters at the relevant wave-lengths should be determined, but these determinations can be carried out in the laboratory under rigorous conditions, including constancy of exposure time.

4. In practical work it is convenient to use the magnitude as a unit of light ratio. The quantity $\log_e (I/I')$ may be converted into a magnitude difference by multiplying by $\frac{5}{2} \log_{10} e = 1{\cdot}086$, and we may then say that the difference of the two light-fluxes is Δm magnitudes where $\Delta m = 1{\cdot}086 \log_e (I/I')$. It is convenient to perform the reductions in terms of magnitudes throughout. For example, as has been explained, a scale is imprinted on the plate by exposing to a series of pairs of light sources with known ratios I_{a1}/I_{a2}, etc. We convert these into magnitude differences Δm_a, etc., and by a change in the unit of γ we get from the pair a a value $\gamma = (D_{a1} - D_{a2})/\Delta m_a$, and so on. We thus obtain the quantities :—

$$\Delta m_\lambda = 1{\cdot}086 \log_e (I_\lambda/I'_\lambda)$$

* Since p is a function of I large changes of I with wave-length will lead to changes in p, and such changes will introduce error. The two sources of light being nearly of the same colour large changes of I, the light flux on the plate, can be avoided by the introduction of a suitable colour filter into the optical train. The filter is of course in position for the exposures on both of the light sources and its absorptions are thus eliminated. It is sufficient to choose the filter so that the densities at the ends of the spectral range used are roughly of the same order.

and we then derive $\Delta\phi$ from the relation :—

$$\Delta\phi = \frac{1}{1{\cdot}086} \cdot \frac{d}{d(1/\lambda)} \cdot \Delta m_\lambda$$

$$\text{i.e. } \Delta\phi = 0{\cdot}921 \times \frac{d}{d(1/\lambda)} \cdot \Delta m_\lambda$$

5. *Relative observations for Gradient.*—The determination of the colour temperatures of stars by the direct comparison of each star with a terrestrial standard would be very tedious in practice. Among the inherent difficulties of such comparisons is the problem presented by the effect of selective atmospheric extinction which reddens the star light, and corrections must be applied to the values of $\Delta\phi$ given by the comparisons. These corrections have to be determined (see section 14) from comparisons between stars photographed at different zenith distances. Further, the atmospheric effects are not constant, but vary from night to night and even from hour to hour. This means that each comparison between star and terrestrial source must be accompanied by a determination of the atmospheric reddening. In addition, the comparisons are tedious, involving as they do the setting up of the artificial comparison star. The direct determination of the colour temperatures of a number of stars in this way is impracticable, if all the precautions essential to the highest accuracy are to be taken.

A more practicable method would be to obtain the value of ϕ for *one* star by means of a series of comparisons with the terrestrial standard. The star in question then becomes the standard for further work, and the values of ϕ for other stars could be obtained by comparison with this standard star. In each of these subsequent comparisons the difficulties arising from atmospheric effects could be avoided by photographing the spectra when the two stars are at equal altitudes.

This last restriction, however, renders the use of a single standard star impracticable. If a single star be employed as standard, Polaris, which would be available for comparison at Greenwich with any star north of 13° north declination, would be the only possibility. But it is desirable that a standard star should be of early type as the relative simplicity of A and B type spectra ensures the absence of systematic error arising from the difficulty of avoiding absorption lines and bands when working with a low dispersion. Consequently Polaris, which is of spectral type F8, and is, moreover, a Cepheid of slightly variable colour temperature is unsuitable as a standard.

Accordingly 25 stars of spectral types A and B, fairly evenly distributed over the northern sky, have been selected to form a Standard System. These have been inter-compared at equal altitudes, each comparison between a pair of standard stars giving the quantity :—

$$\Delta\phi = \phi_1 - \phi_2$$

where ϕ_1 and ϕ_2 are the values of ϕ for the two stars. By means of a series of such comparisons between pairs of standard stars the quantity

$$G = \phi - \phi_0$$

is determined for each of the 25 standards where ϕ_0 is a constant which can be defined by choosing it such that $G = 0$ for a particular star or for the mean of several selected stars. The quantity G is called the *gradient.*

The gradients of the standard stars having been obtained it is now possible to

determine the gradient of any other star by comparison, at equal altitudes, with convenient standards.

To derive colour temperatures from the gradients it is necessary to determine ϕ_0. This must be done by comparisons between stars and a terrestrial source of known colour temperature, but it should be observed that such comparisons are not now undertaken for the purpose of determining the colour temperatures of individual stars; the whole series of them is concentrated on the measurement of the single quantity ϕ_0.

6. *The Telescope and Spectrograph.*—The plates were taken with the 30-inch Cassegrain reflector, the small convex mirror being placed so that its focus coincides with the focus of the main mirror. The focal length of the latter is 137 inches and that of the convex is 24 inches. Consequently a parallel beam of $5\frac{1}{2}$ inches diameter is returned from the convex. This beam passes through a 6-inch hole in the centre of the large mirror, and then falls on a prism of 7 inches height and 40° angle.

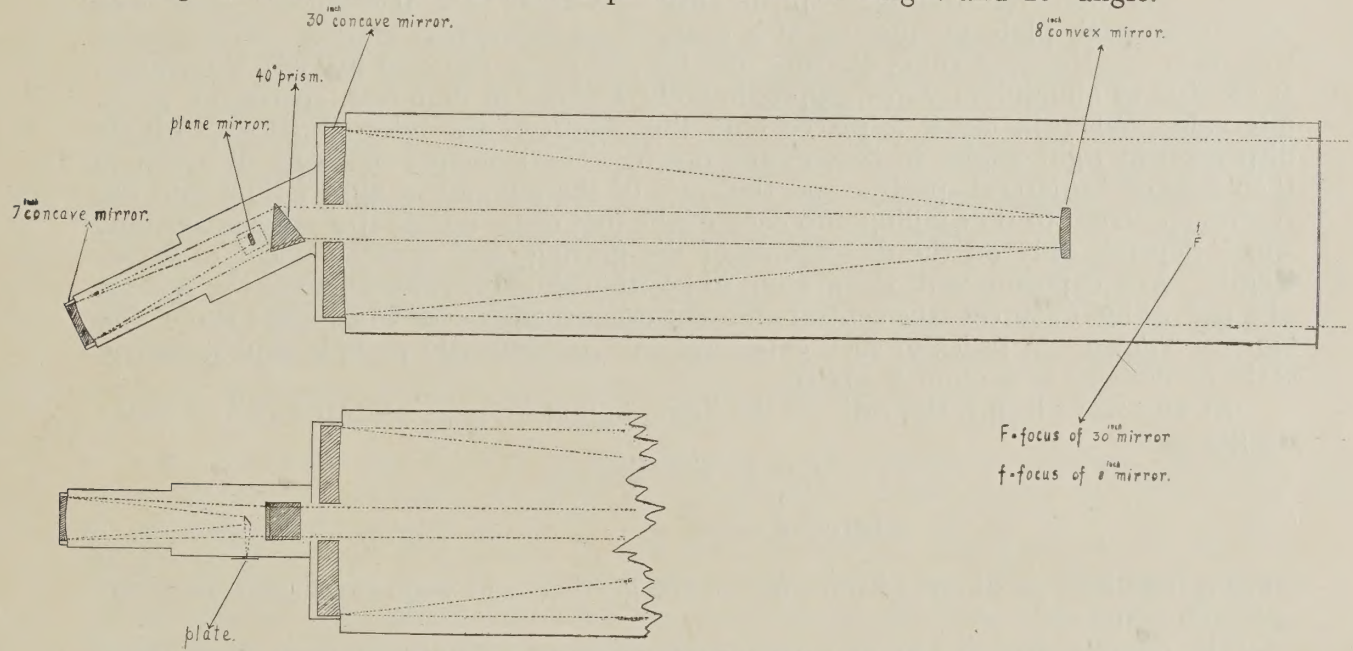

FIG. 4. 30-INCH REFLECTOR WITH SPECTROGRAPH.

In the form originally constructed the rays, after passing through the prism, were focussed by a triplet lens of 6 inches aperture and 27 inches focus. This arrangement was employed up to 1928 January. The lens was photographically corrected and gave excellent definition in the blue region, but the spectra went out of focus in the red. By compromising the focus it was possible to obtain measurements over the spectral range λ 3900 to λ 5800.

In 1928 February the lens was replaced by a concave mirror of 7 inches diameter and 35 inches focus. The dispersed beam falls on this mirror and is then condensed to a focus near the prism. At 6 inches inside focus, the light falls on a small plane diagonal reflector, which directs it onto the photographic plate placed on the side of the camera. The arrangement is illustrated in Fig. 4. Good definition is

obtained throughout the length of the spectrum and with the instrument in this form measurements have been made over the spectral range λ 4139 to λ6486.

It will be noticed that the whole arrangement plays the rôle of a slitless spectrograph, the Cassegrain mirror being the collimator, and the 7-inch concave the image former.

The prism is about 35 inches from the image-forming mirror, and the dispersion is such that the scale of the spectra is 30 mm. from λ 3968 to λ 6563, so that between these limits the 7-inch mirror returns a full beam. The diagonal is, of course, of the requisite dimensions to receive the same length of spectrum. The spectrum is broadened to a suitable width for measurement (0·5mm.) by moving the plate-carrier transversely to the spectrum with a micrometer screw. Alternatively, the whole telescope can be trailed in Right Ascension between appropriate limits which are fixed by wires in the focal plane of the guiding telescope.

7. *The Objective Grating.*—Up to 1929 November, the photometric scale was secured on each plate by the use of a coarse wire diffraction grating. The grating was made by Messrs. Grubb, Parsons and Co., and was received in 1925 November. It consists of aluminium wires, approximately 1·5mm. in diameter, spaced at 3mm. intervals. When in use it is placed over the mouth of the telescope tube, with its dispersion at right angles to that of the prism. The principal spectrum of a star is then flanked by lateral spectra, and the ratio of the amount of light falling into the central spectrum to that falling into each of the first order lateral spectra is a constant which depends only on the dimensions of the grating, and is independent of wave-length. Any exposure with the grating in position thus provides in effect the spectra of a pair of light sources (the central and first order images), for which the ratio of the lights is known. A series of such exposures will consequently provide a photometric scale as defined in section 2 above.

At any wave-length the ratio of the lights falling into the central and first order images is :—

$$I_c/I_l = \pi^2 x^2 / \sin^2 \pi x$$

$$\text{where} \quad x = \frac{s}{s + d}$$

d being the diameter of one of the wires of the grating, and s the clear space between adjacent wires.

The relative sizes of wire and space were measured by micrometer in 23 different regions of the grating, measures of ten wires and ten spaces being taken in each region. From these samples the value of *mean space* ÷ (*mean wire* + *mean space*) came out to be 0·4824. That is :—

$$x = 0{\cdot}4824$$

$$\text{This gives} \quad g = 0{\cdot}895^{\text{m}}$$

$$\text{where} \quad g = 2{\cdot}5 \log_{10} (I_c/I_l)$$

so that g is the difference, reckoned in magnitudes, between the central and first order spectra.

The quantity g is called the *grating constant*, and the value $0{\cdot}895^{\text{m}}$, which was checked by an optical measurement (see section 9 below), was used throughout.

If a gradient $\Delta\phi$ between two stars is being observed, and if the grating is employed for the photographing of each of the spectra, further scaling of the plate will be unnecessary, and the following method of reduction (which does not exactly follow the lines indicated in section 2) is convenient. For any wave-length λ suppose that D_1 and D_2 are the measured densities of the central and first order images of the spectrum of the first star and that D_3 and D_4 are the corresponding densities for the second star. Then if Δm_λ is the difference in magnitudes between the stars at wave-length λ we shall have

$$\Delta m_\lambda = g \times \frac{(D_1 + D_2) - (D_3 + D_4)}{(D_1 - D_2) + (D_3 - D_4)}$$

This formula is necessarily correct when $\Delta m_\lambda = 0$, or when $\Delta m_\lambda = \pm g$. For values of Δm_λ numerically less than g it provides an accurate method of interpolation. It can, in fact, be shown by straightforward algebra that the formula will be rigorously correct if the relation between D and $log\ I$ is of the form

$$D = p + q\ .\ log\ I + r\ .\ (log\ I)^2.$$

So the formula is really a second difference formula of interpolation.

The practice of making every exposure with the grating in position was continued up to 1928 January and the densities were reduced by the formula above. This method is sound, but is very uneconomical of light. With the grating in position the exposure required to bring up the first order spectra to convenient densities is five times the exposure necessary when the grating is not used. From 1928 February to 1929 November each plate was scaled by two grating exposures on a bright star. The values of γ for the densities required were deduced by linear interpolation and applied to the measures of the fainter stars on the plate, these being photographed without the grating. But even this procedure involves the expenditure of valuable observing time on the operation of scaling, and a method was accordingly devised whereby this operation was transferred to the laboratory.

8. *The Scale Spectrograph.*—The scales are now printed on the plate by means of a spectrograph specially designed for the purpose. Light from a diffusing screen A (see Fig. 5), illuminated by an electric lamp, falls upon the slit B of the spectrograph. The rays proceeding from the slit are deflected by a diagonal C on to a concave mirror D of 5 inches aperture and 19 inches focus, the slit being in the primary focus of this mirror. The reflected parallel beam impinges on the front surface of a prism E of 30° angle, the back surface of which is silvered. After reflection at this surface, the light passes back through the prism and the dispersed beam is then reflected a second time by the mirror D. The rays now pass over the prism C and come to focus on the plate at F. The scale of the spectrum is approximately the same as in the slitless spectrograph used for the stars.

The slit is a multiple slit, and consists of three slits (see diagram) whose breadths are approximately in the ratio of 1 : 2 : 4. Each exposure thus gives three spectra, and for any wave-length the light fluxes in these three spectra are approximately in the ratio of 1 : 2 : 4.

The light from the diffusing screen passes through a circular aperture of 2 inches diameter on its way to the multiple slit. This aperture is close to the diffusing screen. Two shutters are arranged so that either the top or bottom half of the aperture can be

obscured, the shutters coming up against stops which are placed so that the two shutters just meet when both are closed.

Suppose now exposures be made with a full aperture and with each of the two half apertures, the exposure time being the same throughout. If each of the shutters cuts off exactly half the beam, and if the beam itself and the optical train were perfectly symmetrical, the light fluxes in the cases of the two exposures with the half apertures would be equal, and either of these light fluxes would be exactly half the light flux for the exposure with full aperture. On account of irregularities in the beam and optical train it will not happen that the light fluxes for the two half aperture exposures will be exactly equal, but it will still be true that the mean of these light fluxes will be exactly half the flux for the exposure with full aperture.

Denoting the three components of the multiple slit by a, b and c consider the spectra photographed through slit a. At a given wave-length let D_{a_1} be the density of the spectrum photographed through the full aperture and let D_{a_2} be the mean of

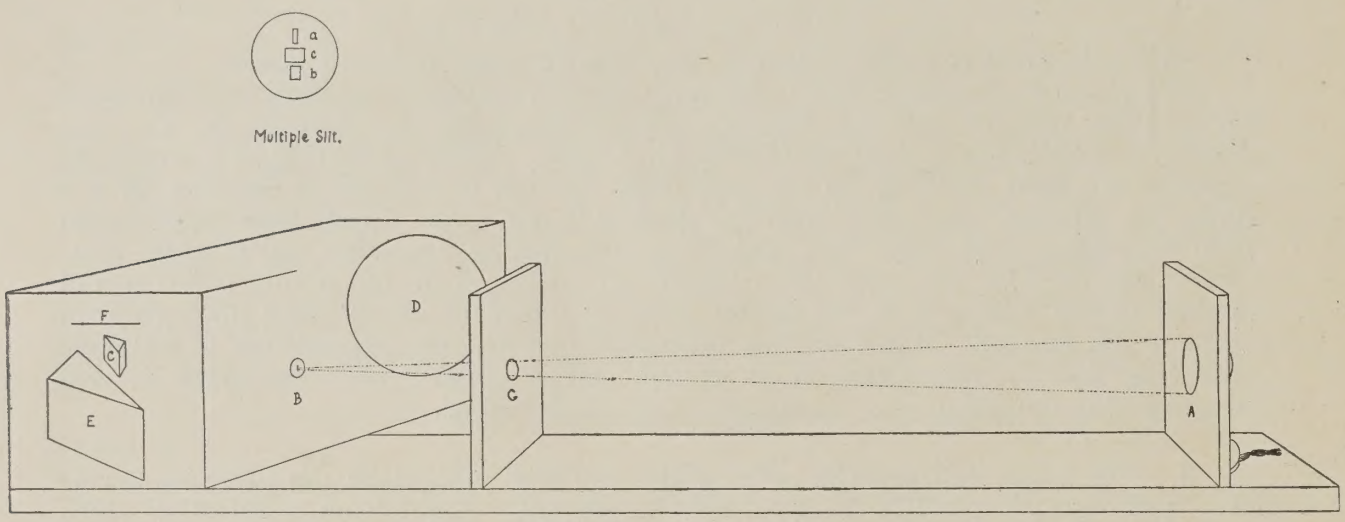

FIG. 5. SCALE SPECTROGRAPH.

the corresponding densities for the half aperture exposures. The corresponding light fluxes will be I_{a_1}, and I_{a_2} where $I_{a_1} : I_{a_2} = 2 : 1$ exactly. Similarly for slits b and c. A photometric scale is thus obtained as described in Section 2, being derived from the fundamental 2 : 1 light ratio.

The scale being thus set up, it can be utilised if required for measuring the light ratios $I_a : I_b : I_c$ when a single exposure is made with the multiple slit. These ratios having been determined by exposures with full and half apertures on one plate they can be transferred to another plate if desired, and a scale can thus be printed on the second plate from a knowledge of the ratios $I_a : I_b : I_c$ without further use of the full and half apertures.

To guard against errors arising from large variations of light flux with wave-length, referred to on page 9, provision is made for the insertion of colour filters in the beam at G. A suitable filter is inserted which has the effect of roughly equalising the colour of the scales with that of the stars to which they are to be applied.

The arrangement of the scale spectrograph is illustrated in the diagram. The plates taken with the telescope were usually inserted in the scale spectrograph and scaled on the following day.

The scale spectrum is of course continuous. In order to fix the position of the wave-lengths required a wire is placed just in front of the plate and its silhouette gives a convenient reference mark. Provision is made for throwing an image of a hydrogen discharge on the slit and from its spectra the scale of the dispersion and the wave-length corresponding to the silhouette of the wire is determined (*see frontispiece*).

9. *Calibration of Grating.*—The method of establishing a fundamental 2 : 1 light ratio by the use of full and half apertures was also employed for the purpose of a direct calibration of the grating constant. The telescope was trained on an artificial star mounted 600 feet away on the roof of the Octagon Room. With two semi-circular stops, each of which covered half the aperture of the 30-inch reflector, exposures were made on the artificial star with the full aperture and with the two half-apertures successively, the exposure time being the same in each case. All the exposures were made through the grating.

As in the case of the scale spectrograph the full aperture against the mean half-aperture gives a light ratio of 2 : 1, that is a magnitude difference of 0·75 magnitudes. This gave an independent scale from which the grating constant could be determined. The results from five plates taken in 1927 February were as follows, measures having been taken at a number of wave-lengths in the case of each plate :

VALUES OF GRATING CONSTANT

Plate	g
I	0·90
II	0·90
III	0·92
IV	0·90
V	0·89
	mean 0·90

The agreement of the value of g determined in this way, with the value (0·895) derived from micrometer measures, is satisfactory.

10. *The Micro-Photometer.*—The micro-photometer in which the plates were measured was constructed on the principle proposed by M. Jules Baillaud.* In the Greenwich instrument an image of a straight incandescent tungsten filament is projected on the plate by means of a microscope objective A (see Fig. 6). The rays are then parallelised by a second objective B, and after reflection by the diagonal of a Lummer-Brodhun cube are brought to focus at F by a third objective C. A beam of light from a second lamp, similar to the first and in parallel circuit, is passed through a graduated wedge, and then passes successively through an objective D, the Lummer-Brodhun cube and the objective C. The wedge being in the principal focus of objective D an image of the wedge will be formed at F, coincident with the images of the filament and the plate. The amount of light from plate and wedge is defined by a stop placed at F, and the rays pass through this stop into a small viewing telescope which is

* *Bulletin de la Société Astronomique de France*, Vol. 28, p. 28, 1914.

focussed on the surface of the objective C. Through this telescope the cube is observed illuminated by parallel light, the central disc of which consists of light from the straight filament and the outer annulus of light which has passed through the wedge. An auxiliary viewing eyepiece is attached which when swung into position enables the measurer to view the plate.

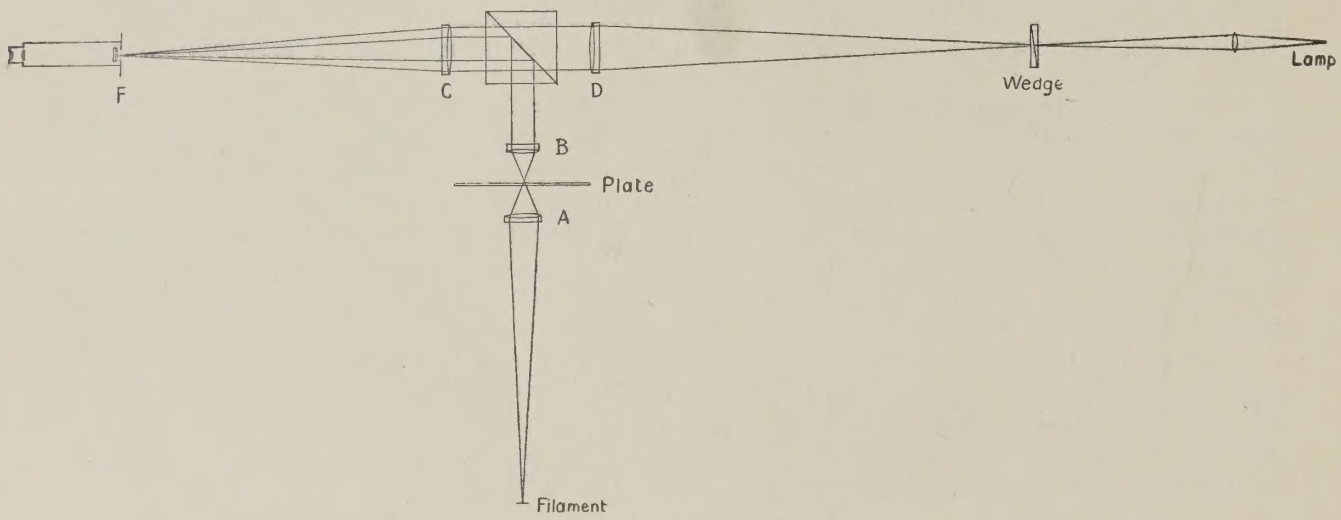

FIG. 6. SCHEMATIC DIAGRAM OF MICRO-PHOTOMETER.

The plate is placed on a carrier which is provided with adjustment for orientation, and which is capable of motion in two perpendicular directions. By means of one of these motions each spectrum successively can be brought into position for measurement, and by means of the other, to which a micrometer screw is attached, any wave-length of the spectrum may be set off. In the measuring position the image of the filament lies across the spectrum, its effective length being limited by the stop at F.

Measurement of density is made by adjusting the wedge so that the two zones of light viewed through the small telescope are of equal intensity. The wedge is then read. Readings taken with the filament image on the background of the plate give the zero reading which is subtracted from the wedge readings to obtain densities.

The portion of the spectrum whose density is being measured thus consists of a rectangle whose breadth is the diameter of the image of the incandescent filament on the plate (about 0·03mm.) and whose length is limited by the stop at F.

All plates were measured by two measurers.

11. *Experiments on the effect of exposure time.*—When photographing spectra with the telescope, the exposure times were adjusted so as to give convenient densities. The density measurements, however, were treated just as if they appertained to spectra photographed with the same exposure time. In order to test the legitimacy of this procedure a series of comparisons of a bright star against itself were made. In these

observations, to which reference has already been made in Section 3, the star was photographed first with and then without the objective grating in position, the exposure times being chosen so as to give comparable densities. The spectrum photographed without the grating was compared with either the central or first order spectrum of the longer exposure (the one which gave the closest match in density being selected) and values of $\Delta\phi$ were deduced from the measures of density. The results from 20 plates are as follows :—

VALUES OF $\Delta\phi$. LONG EXPOSURE MINUS SHORT

	Star	*Exposure Times*		$\Delta\phi$
1	α Lyræ	112^s	14^s	+ ·05
2	α Cygni	10^m	52^s	+ ·08
3	α Cygni	8^m	28^s	— ·02
4	α Cygni	8^m	28^s	·00
5	α Cygni	8^m	28^s	— ·02
6	α Cygni	8^m	28^s	— ·04
7	α Cygni	8^m	28^s	— ·04
8	α Cygni	8^m	28^s	— ·04
9	α Cygni	10^m	28^s	+ ·05
10	α Cygni	8^m	28^s	+ ·01
11	α Cygni	8^m	28^s	+ ·02
12	α Cygni	8^m	28^s	— ·03
13	α Cygni	8^m	28^s	+ ·04
14	α Cygni	8^m	28^s	+ ·01
15	α Aquilæ	5^m	28^s	+ ·04
16	α Aquilæ	5^m	28^s	+ ·04
17	α Aquilæ	5^m	28^s	+ ·03
18	α Aquilæ	5^m	28^s	+ ·14
19	α Aquilæ	6^m	28^s	— ·10
20	α Aquilæ	6^m	28^s	+ ·02
				mean + 0·012 ± ·008

It should be observed that throughout this series the densities at the blue and red ends of the spectral range used were comparable.

The conclusion to be drawn has already been stated on p. 9. When small differences of colour are being measured, and when care is taken to secure approximate equality of density at the ends of the spectral range used, a certain amount of latitude in exposure time is permissible, and spectra photographed with unequal exposure times can be measured and reduced as if the times were equal.

12. *The Standard System.*—The twenty-five standard stars are all of types A and B. It is desirable that standard stars should be of early type, as the relative simplicity of their spectra ensures the absence of systematic error arising from the difficulty of avoiding absorption lines and bands in work with low dispersion.

The scheme of observation employed is illustrated by Fig. 7 in which a line joining two stars denotes a series of comparisons. In all 708 comparisons between 186 pairs of standards were secured.

The spectra were measured at a number of points, selected so as to be clear of absorption lines. At the commencement of the work in 1926 Marion Iso-Record plates were used. These plates are sensitive to the yellow, but have a region of low sensitivity in the green. Measurements were made at eight points in the blue, extending from λ 3994 to λ 4204 ; at four points on the blue side of the minimum in the green, extending from λ 4952 to λ 5073, and at four points in the yellow extending from λ 5454 to λ 5624.

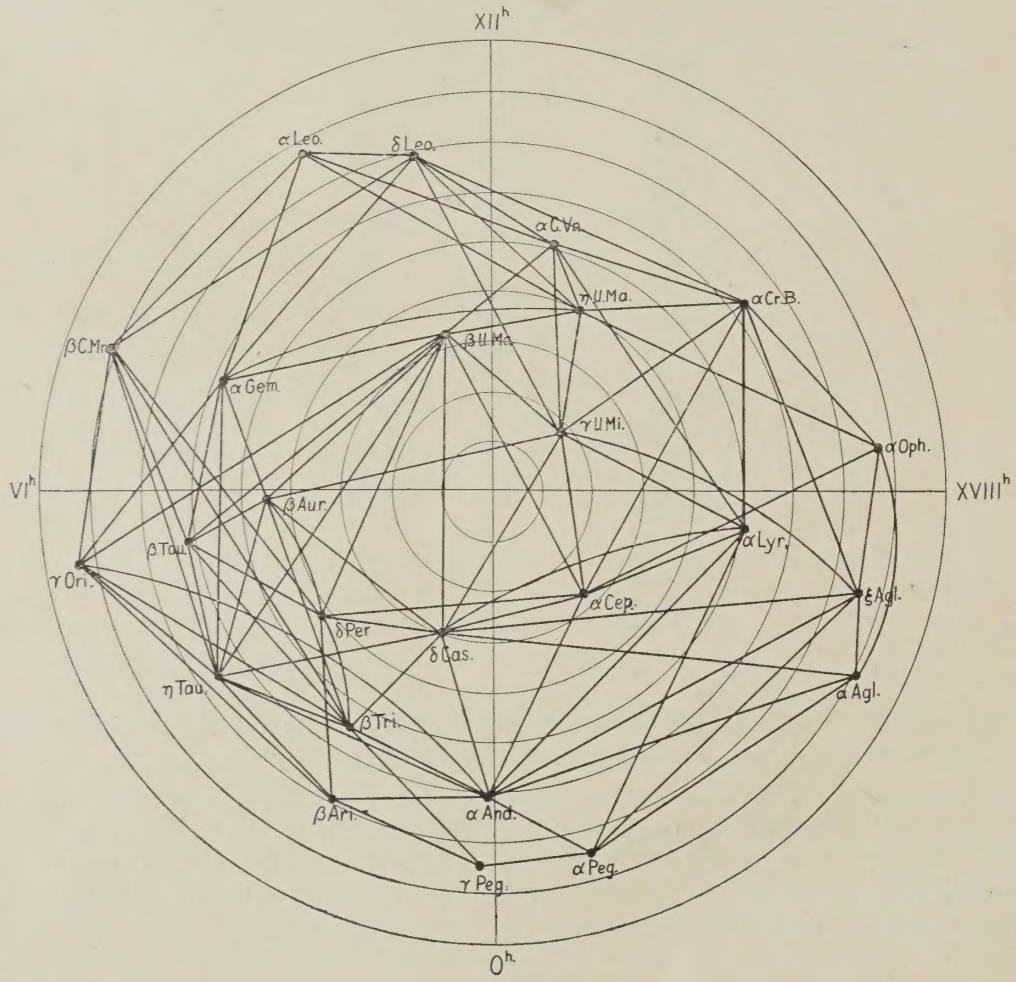

FIG. 7. INTERCOMPARISON OF STANDARD STARS.

At a later stage Ilford Panchromatic plates were used, giving a more even sensitivity curve and also a longer range of wave-lengths. The measurements were made as before in the blue, and at eight points in the yellow extending from λ 5385 to λ 5789, good focus having been secured for the blue and yellow regions. During this earlier work the precise wave-lengths used were re-adjusted several times.

In 1928 February, the reflecting spectrograph was brought into operation and subsequent to this date measurements were made at the following points :—

	Blue		Red
	λ		λ
1 ..	4139	1 ..	6082
2 ..	4155	2 ..	6215
3 ..	4194	3 ..	6273
4 ..	4209	4 ..	6318
4a ..	4253	5 ..	6364
5 ..	4266	6 ..	6395
6 ..	4279	7 ..	6443
7 ..	4429	8 ..	6486
8 ..	4509		

Of the nine points given in the blue, eight were utilised for each comparison. When one of the stars compared was of type B, point number 1 in the blue region was not used, it being too near to the helium line λ 4144, and point number 4a at λ 4253 was substituted.

Denoting the mean values of $1/\lambda$ (λ being now expressed in microns) for the two sets of eight points by $1/\lambda_B$ and $1/\lambda_R$, the difference of gradient $\Delta\phi$ between the two stars will be given by :—

$$\Delta\phi = \phi_1 - \phi_2 = -\frac{\Delta m_B - \Delta m_R}{1/\lambda_B - 1/\lambda_R} \times 0{\cdot}921$$

where Δm_B and Δm_R denote the means of the quantities $1{\cdot}086\ log_e\ (I_1/I_2)$ for the two sets of wave-lengths, the suffices 1 and 2 referring to the two stars.

The measured gradient $\Delta\phi$ between each pair of stars has to be corrected for the effect of atmospheric reddening unless the zenith distances z_1 and z_2 at which the spectra were photographed are exactly equal. The correction to be applied may be assumed to be of the form

$$A(sec\ z_2 - sec\ z_1)$$

The whole question of atmospheric reddening is discussed in a subsequent section in connection with the comparisons of the standard stars with a terrestrial standard. For the present it suffices to say that A will vary from night to night and will also depend on the wave-length used. But for the purpose of the intercomparisons between the standard stars an average value can be adopted. In these intercomparisons z_1 and z_2 are nearly equal and the corrections are always small with the result that admissible departures from the adopted values of A can be safely included with the other accidental errors. The following values have been adopted.*

Up to 1928 January $A = 0{\cdot}72$

Subsequent to 1928 January $A = 0{\cdot}50$

The results of the Standard Star intercomparisons are set forth in detail on pages 41 to 53. A least square solution gave the following values of the gradients G. The table also gives the Harvard spectral types for these stars.

* See p. 28.

GRADIENTS OF STANDARD STARS

	Star	Spectral type	G		Star	Spectral type	G
1	α Andromedæ	Aop	−·100	14	β Ursæ Majoris	Ao	−·019
2	γ Pegasi	B2	−·297	15	δ Leonis	A3	+·292
3	δ Cassiopeiæ	A5	+·248	16	α Canum Ven. (bright component)	Aop	−·057
4	β Arietis	A5	+·291				
5	β Trianguli	A5	+·292	17	η Ursæ Majoris	B3	−·232
6	δ Persei	B5	−·158	18	γ Ursæ Minoris	A2	+·193
7	η Tauri	B5p	−·016	19	α Coronæ Bor.	Ao	+·005
8	γ Orionis	B2	−·237	20	α Ophiuchi	A5	+·301
9	β Tauri	B8	−·138	21	α Lyræ	Ao	−·003
10	β Aurigæ	Aop	+·061	22	ζ Aquilæ	Ao	+·035
11	β Canis Minoris	B8	−·017	23	α Aquilæ	A5	+·421
12	α Geminorum (mean of components)	Ao	+·107	24	α Cephei	A5	+·435
				25	α Pegasi	Ao	−·030
13	α Leonis	B8	−·085				

The intercomparisons only give the differences of gradient between the standard stars, and the zero of the gradient system is thus arbitrary. It has been defined so that the mean gradient of the 9 stars of type Ao (or Aop) on the standard list is zero.

A discussion of the residuals gives $\pm$·05 as the probable error of a single comparison. The average probable error of the gradients in the above table is about $\pm$·012.

The star *a* Cygni (A2p) was originally intended for use as a standard star. The observations of this star, however (which are set forth on p. 54), appear to indicate that the star is of variable colour and accordingly it has been excluded from the standard list.*

13. *Absolute observations.*—The relative gradients of the standard system having been obtained, it remains to determine the colour temperature corresponding to zero gradient. This quantity can only be measured by comparisons of standard stars with a terrestrial source of light of known colour temperature. Each such comparison will yield the value of ϕ for the standard star concerned, and if G be its gradient, referred to the zero of the standard system, we shall have

$$\phi_0 = \phi - G$$

where ϕ_0 refers to the zero of the standard system. ϕ_0 having been determined from the mean of a series of such observations, the application of the gradients gives the values of ϕ, and so of T for each of the standard stars. The values of ϕ and T for any star which has been compared with one or more of the standard stars can also be obtained once ϕ_0 has been determined.

The comparison source of light used was an Eastman Kodak Standard Acetylene Burner which, when fed with acetylene at a pressure of 9 cms. of water, gives a cylindrical flame of about 3 mm. diameter and 5 cms. height. The flame is surrounded by a

* It was included in a list of gradients of Standard Stars published in the *Monthly Notices of the Royal Astronomical Society* for March, 1927. Since that date γ Orionis and β Canis Minoris have been added to the Standard List and a series of additional comparisons obtained. The method of defining the zero of the gradient system has been changed, the 1927 values being on the average +·040 greater than those now given.

black cylindrical hood of metal with a small aperture on one side, through which the flame is viewed. An adjusting screw provides the means of bringing any desired portion of the flame opposite the aperture. The screw is set so as to utilise that portion of the flame which gives maximum candle power.

From the work of Hyde, Forsythe and Cady,* it appears that when the burner is fed with pure acetylene at a pressure of 9·0 cms. of water, with the setting screw adjusted to maximum candle power, it will radiate between wave-lengths 0·4μ and 0·7μ as a grey body at a colour temperature of 2360° K.

The source of supply used was 'Dissolved Acetylene,' supplied by Messrs. Allen Liversidge in cylinders. These cylinders contain acetylene dissolved in acetone under high pressure. After being admitted through an adjustable pressure controlling valve the gas was passed through bottles containing sodium bisulphite in solution, with the object of removing acetone, then through a drying bottle containing (1) caustic potash and (2) calcium chloride, the caustic potash removing sulphur dioxide from the gas. The acetylene was then fed into the burner, the pressure being read by a water manometer and adjusted to 9·0 cms. by the pressure controlling valve.

The burner was mounted in a small hut on the roof of the Octagonal Building 600 feet from the telescope. By means of a circular hole of 2 mm. diameter an image of the flame, as viewed through the aperture in the metal sheath was projected on a screen, the image being centred on a second aperture through which passed a cone of rays which completely filled the telescope.

The spectra of the stars and flame were measured at 20 wave-lengths, arranged in five groups of four wave-lengths each as follows :—

Group	λ (in microns)	$1/\lambda$	Mean
I.	0·4429	2·257	2·223
	0·4460	2·242	
	0·4485	2·230	
	0·4619	2·165	
II.	0·4779	2·092	2·063
	0·4798	2·084	
	0·4820	2·075	
	0·5001	2·000	
III.	0·5234	1·911	1·884
	0·5284	1·893	
	0·5334	1·875	
	0·5384	1·858	
IV.	0·5720	1·748	1·730
	0·5760	1·736	
	0·5800	1·724	
	0·5840	1·712	
V.	0·6364	1·571	1·557
	0·6395	1·564	
	0·6443	1·552	
	0·6486	1·542	

* *Physical Review*, Vol. 14, p. 379, 1919.

The measurements for the individual wave-lengths within each group were meaned, so that five values of Δm_λ for *acetylene — star* can be obtained from each comparison. The five equations of condition

$$-\frac{1}{\lambda}\cdot\Delta\phi + k = \Delta m_\lambda$$

can then be formed and a least square solution will give $\Delta\phi$.

The difference of colour between the acetylene and the stars is considerable, and, as was pointed out in Section 4, this may be a source of error when constancy of exposure time is not maintained over a plate. The colour difference was reduced to a small amount by the insertion of a blue filter in the beam from the burner, this filter being mounted in a tube placed about ten feet from the burner and adjusted so that the cone of rays passed through it.

If now $\Delta m'_\lambda$ be the measured magnitude difference for *acetylene — star* on the plate then

$$\Delta m_\lambda = \Delta m'_\lambda + B_\lambda$$

where B_λ is the absorption, in magnitudes, of the filter. The Δm_λ can then be substituted in the equations of condition given above from which $\Delta\phi$ is derived.

14. *Measurement of the colour filters.*—The absorptions B_λ were measured with the scale spectrograph. The filter was inserted into the beam and exposures made with full and half apertures as described in Section 8. The filter was then removed and a piece of blackened gauze substituted and exposures with full and half apertures made. The exposure time was the same throughout.

The object of the gauze is to avoid the measurement of large magnitude differences. For a given wave-length exposures taken with and without the colour filter would give on measurement the value of B_λ. But some of the B_λ are large and difficult to measure accurately. They can be reduced, however, by means of a neutral filter, such as the blackened gauze. When this is employed the quantity which is measured is

$$B'_\lambda = B_\lambda - C$$

where C is the absorption of the gauze, and is assumed, in the first place, to be independent of wave-length. B'_λ can be inserted instead of B_λ in the equations of the last Section, the introduction of the constant quantity C not affecting the value of $\Delta\phi$.

The quantities to be measured can be reduced still further by means of (1) the fundamental intervals of 0·75 magnitudes (corresponding to a light ratio of 2 : 1) which are realised by the use of full and half apertures, and (2) by the magnitude intervals between the exposures taken with the three components of the multiple slit. Suppose, for example, that at a certain wave-length the density D for the filtered beam taken with full aperture and slit c is comparable with the density D' for the unfiltered beam with half aperture and slit a. Suppose further that the differences between slits a and b and between slits b and c have been measured and that their values have come out to be say 0·78 magnitudes and 0·74 magnitudes. When $D'-D$ is divided by the appropriate value of γ suppose a small magnitude difference μ_λ is obtained. We should then have :—

$$\begin{aligned} B'_\lambda &= \mu_\lambda + 0{\cdot}75 + 0{\cdot}78 + 0{\cdot}74 \\ &= \mu_\lambda + 2{\cdot}27 \end{aligned}$$

Two filters were employed during the course of the observations. Up to and including 1931 May 12, a Wratten 78, which made the colour of the acetylene flame approximately that of a *G*0 star, was used. Subsequently a combination of a Wratten 78 and a Wratten 78A, which made the flame very similar to an *A*0, was employed. The measurements were naturally made at the same 20 wave-lengths as before, and the result averaged for each of the five groups. The measured values of B'_λ are as follows; a constant has been applied to the results from each plate which makes the mean B'_λ for the five groups zero.

The determinations were spread over the period during which the filters were in use.

SELECTIVE ABSORPTIONS. VALUES FOR FILTER 78

Plate	Group I	II	III	IV	V
	m	m	m	m	m
1	−1·09	−0·75	+0·06	+0·66	+1·12
2	−1·11	−0·75	+0·06	+0·65	+1·15
3	−1·05	−0·75	+0·04	+0·64	+1·12
4	−1·05	−0·74	+0·03	+0·66	+1·11
5	−1·09	−0·75	+0·04	+0·65	+1·15
6	−1·03	−0·77	+0·04	+0·63	+1·13
7	−1·07	−0·71	+0·02	+0·64	+1·13
Mean ..	m −1·070	m −0·746	m +0·041	m +0·647	m +1·130

SELECTIVE ABSORPTIONS. VALUES FOR FILTER 78 + 78A

Plate	Group I	II	III	IV	V
	m	m	m	m	m
1	−1·56	−1·14	+0·04	+0·97	+1·67
2	−1·59	−1·13	+0·03	+0·97	+1·70
3	−1·57	−1·16	+0·04	+0·97	+1·74
4	−1·56	−1·13	+0·05	+0·95	+1·69
5	−1·60	−1·18	+0·03	+1·02	+1·72
6	−1·55	−1·09	+0·07	+0·94	+1·65
7	−1·58	−1·14	+0·04	+0·99	+1·68
8	−1·54	−1·09	+0·03	+0·95	+1·67
9	−1·55	−1·12	+0·04	+0·96	+1·68
10	−1·61	−1·18	+0·08	+1·00	+1·68
11	−1·58	−1·14	+0·07	+0·98	+1·67
Mean ..	m −1·572	m −1·136	m +0·047	m +0·973	m +1·686

The mean results for the five groups were applied to the measured magnitude differences between the filtered acetylene and the stars, and the values of $\Delta\phi$ for *acetylene — star* deduced as indicated in the previous Section.

In the foregoing, the absorption C of the blackened gauze was assumed to be independent of wave-length. To test this a series of plates was taken with the scale spectrograph with and without the gauze inserted in the beam, comparisons being made between the spectra taken with slit *c* and full aperture for the one case and spectra taken with slit *a* and half aperture in the other. The results for the five groups are as follows, a constant having been subtracted from the five group means for each plate, as was done for the filter absorptions.

GAUZE

Plate	Group I	Group II	Group III	Group IV	Group V
	m	m	m	m	m
1	−·01	+·02	·00	−·01	+·02
2	−·02	−·05	+·01	+·02	+·05
3	·00	·00	·00	·00	+·02
4	−·09	−·05	+·01	+·04	+·09
5	+·01	−·01	−·01	+·01	·00
6	−·01	+·01	−·03	−·03	−·02
7	−·02	−·02	−·01	−·02	−·01
8	+·04	+·04	+·01	−·02	−·05
9	+·04	+·02	+·01	−·01	−·05
10	+·03	−·02	−·02	·00	·00
Mean ..	m −0·003	m −0·006	m −0·003	m −0·002	m +0·005

The group means are all in the third decimal place of a magnitude and may be taken as confirming the assumed neutrality of the gauze.

15. *Atmospheric Reddening.*—In the comparison of the acetylene flame with a star, the observed values of $\Delta\phi$ must be corrected for the effect of atmospheric reddening.

If at wave-length λ the observed difference for *acetylene — star* is Δm_λ then Δm_λ will be too large by an amount α_λ, where α_λ is the extinction, measured in magnitudes, of the earth's atmosphere.

If the layers of equal extinction coefficient be horizontal then at zenith distance z,

$$\alpha_\lambda = A_\lambda \sec z$$

where A_λ is the extinction at the zenith. A_λ may be regarded as the sum of $A_{1\lambda}$ and $A_{2\lambda}$ where $A_{1\lambda}$ is proportional to the air mass and $A_{2\lambda}$ represents the effect of additional scattering by dust in the lower strata.

This formula will break down when z approaches 90°, like the tangent formula in refraction, but as far as $A_{1\lambda}$ is concerned, is correct down to $z = 70°$ to within one per cent* and *a fortiori* the same will be true for $A_{2\lambda}$.

* See *Smithsonian Miscellaneous Collections*, Vol. 71, p. 419, Table 556.

Suppose that the A_λ have been determined for the same values of λ as have been employed in the *acetylene — star* comparisons. A straightforward procedure would then be to correct the observed Δm_λ by the quantities $-\alpha_\lambda$ and then to deduce $\Delta\phi$ from a least square solution of the corrected values.

The following procedure, however, gives the same result, and is more convenient. Solve the uncorrected values of Δm_λ for gradient giving

$$\Delta\phi_1 = -\frac{d}{d(1/\lambda)}.\Delta m_\lambda$$

Solve also the values of A_λ for gradient in the same way giving

$$A = +\frac{d}{d(1/\lambda)}A_\lambda$$

Then $\Delta\phi$ is given by $\Delta\phi = \Delta\phi_1 + A\sec z$

The value of A could be obtained by photographing a star at two zenith distances z_1 and z_2 and reducing the measures of the spectra just as if they were the spectra of two stars. If the value of $\Delta\phi$ so obtained be $\phi_1 - \phi_2$ then

$$A = (\phi_1 - \phi_2)/(\sec z_1 - \sec z_2)$$

It is important that A be obtained by measurements at the same wave-lengths as the comparisons to which it is to be applied. This is necessary since the A_λ do not vary linearly with $1/\lambda$. In the case, therefore, of a comparison between the acetylene flame and a star, the atmosphere introduces curvature into the comparison and also into the measures taken to determine A. When the gradient $\Delta\phi_1$ for *acetylene — star* is corrected by the gradient $A\sec z$ these curvatures will only cancel if both gradients have been derived from measures at the same wave-lengths.

The curvature is thus immaterial to the derivation of colour temperatures from measures at a selected series of wave-lengths. It becomes important, however, if it be desired to investigate the closeness with which the energy distribution of the stars conforms to the black body law. It will then be necessary to evaluate, for each wave-length, the residuals from the derived gradient between acetylene and star and to correct them, by the corresponding residuals, for atmospheric reddening.

To determine A by two exposures on the same star at different zenith distances a considerable period must be allowed to elapse between the exposures, a procedure which is impracticable in a variable climate. The plan which has been adopted is to photograph a standard star P as near the zenith as possible, and then to photograph on the same plate another standard star Q at zenith distance of 50° to 60°. These spectra are compared giving an observed difference of gradient $\delta\phi'$ say.

But the true gradients G_P and G_Q of these stars are known from the intercomparisons, at equal altitudes, of the standard stars, which have been described in Section 12. We then have

$$A = \frac{\delta\phi' - (G_P - G_Q)}{\sec z_P - \sec z_Q}$$

where z_P and z_Q are the zenith distances.

In practice the following spectra were successively photographed on each plate.

1. A standard star Q at a zenith distance of 50° to 60°.
2. A standard star P near the zenith.
3. A standard star R at a zenith distance of 50° to 60°.

The stars Q and R were usually chosen so as to be east and west of the meridian. The spectrum of the acetylene flame was photographed on the same plate.

The atmospheric reddening was determined by comparisons between P and Q, and between P and R, measures being made at the 20 wave-lengths (5 groups of 4) listed on p. 21. The results are as follows :—

OBSERVATIONS TO DETERMINE ATMOSPHERIC REDDENING

Date	High Stars		Low Stars		Azimuth	$\Delta\phi$ Low-High Corrected for difference of Gradient	$\sec z_2 - \sec z_1$	A (mean)
	Name	Z.D. z_1	Name	Z.D. z_2				
1931								
April 11	β U. Maj.	6°·5	β Taur.	57°·8	W	+·549	·87	
			α Cor. B.	58·9	E	+·545	·93	·63
April 11	β U. Maj.	5·2	α Cor. B.	57·6	E	+·615	·86	
			β Auri.	50·8	NW	+·306	·58	
April 13	η U. Maj.	5·5	α Gemi.	61·1	WNW	+·420	1·07	·31
			α Ceph.	55·9	NNE	+·129	·78	
April 17	β U. Maj.	5·2	α Cor. B.	56·9	E	+·532	·83	·64
			β Auri.	50·3	NW	+·356	·56	
April 30	η U. Maj.	10·2	α Cor. B.	41·8	ESE	+·106	·33	·29
			α Gemi.	59·9	WNW	+·283	·98	
May 5	η U. Maj.	2·6	α Leon.	56·2	WSW	+·192	·80	·28
			α Ophi.	54·6	ESE	+·242	·72	
May 6	η U. Maj.	12·0	α Ophi	50·9	ESE	+·265	·56	
			δ Leon.	55·6	W	+·371	·75	·48
May 6	γ U. Min.	20·6	δ Leon.	57·6	W	+·370	·78	
			ζ Aqil.	52·0	ESE	+·251	·56	
May 12	η U. Maj.	2·9	α Leon.	59·0	WSW	+·279	·94	
			α Ophi.	55·2	ESE	+·289	·75	·32
May 12	γ U. Min.	21·0	α Ophi.	53·6	ESE	+·268	·61	
			δ Leon.	55·2	W	+·128	·68	
May 28	γ U. Min.	20·4	δ Leon.	54·0	W	+·151	·63	
			ζ Aqil.	54·7	ESE	+·175	·66	·27
May 28	γ U. Min.	21·6	ζ Aqil.	52·4	ESE	+·171	·57	
			β U. Maj.	46·5	NW	+·115	·38	

OBSERVATIONS TO DETERMINE ATMOSPHERIC REDDENING—*continued.*

Date	High Stars		Low Stars		Azimuth	$\Delta\phi$ Low-High Corrected for difference of Gradient	$\sec z_2 - \sec z_1$	A (mean)
	Name	Z.D. z_1	Name	Z.D. z_2				
June 12	γ U. Min.	21·6	α Aqil.	61·9	ESE	+·477	1·05	·45
			δ Cass.	61·7	NNE	+·461	1·03	
June 17	α Lyra.	13·8	δ Cass.	54·1	NE	+·042	·67	—·04
			α C. Ven.	57·7	WNW	—·094	·84	
July 3	α Lyra.	13·4	δ Cass.	55·4	NE	+·355	·73	·36
			β U. Maj.	58·4	NNW	+·246	·88	
July 6	α Lyra.	13·1	β U. Maj.	58·7	NNW	+·119	·90	·13
			α Andr.	59·9	E	+·127	·97	
July 11	α Lyra.	16·5	δ Cass.	58·9	NNE	+·102	·89	·10
			β U. Maj.	54·0	NW	+·108	·66	
July 11	α Lyra.	13·1	β U. Maj.	56·4	NW	+·021	·78	
Nov. 1	α Ceph.	14·1	β Aris.	53·8	E	+·227	·66	·25
			α Aqil.	54·9	SW	+·190	·70	
Nov. 1	α Ceph.	19·8	η Taur.	58·8	E	+·201	·87	
			α Lyra.	57·1	WNW	+·215	·78	
Nov. 1	δ Cass.	10·6	α Lyra.	58·2	WNW	+·169	·88	

The mean value of A for the 14 nights is 0·32.

The negative value for June 17 must be erroneous. It is to be ascribed to accidental error and accordingly has been included in the mean.

Previously a series of determinations of atmospheric reddening had been carried out in 1926 April to August. Comparisons were made on various occasions between α Lyræ and ε Ursæ Majoris, and between α Lyræ and ζ^1 Ursæ Majoris. The spectra were measured over the range λ 3994 to λ 5624, the same wave-lengths being used as were being employed for other comparisons made at that time (see page 18).

The results are as follows, z_1 denoting the zenith distance of α Lyræ, and z_2 that of the other star.

OBSERVATIONS FOR DETERMINATION OF A

(λ 3994 to λ 5624)

α Lyræ — ϵ Ursæ Majoris		α Lyræ — ζ^1 Ursæ Majoris	
$\Delta\phi$	$sec\ z_1 - sec\ z_2$	$\Delta\phi$	$sec\ z_1 - sec\ z_2$
+0·13	+0·33	+0·46	+0·74
+0·63	+0·71	+0·06	+0·31
+0·87	+0·80	+0·59	+0·75
+0·68	+0·82	+0·11	+0·36
−0·30	−0·36	+0·08	+0·40
−0·10	−0·32	−0·50	−0·35
−0·20	−0·26	−0·20	−0·34
−0·26	−0·22	−0·26	−0·25
−0·54	−0·94	−0·38	−0·22
−0·43	−0·41	−0·41	−0·79
−0·53	−0·71	−0·52	−0·52
−0·34	−0·58	−0·35	−0·68
		−0·27	−0·52

Denote by ϕ_1, ϕ_2, ϕ_3 the values of ϕ for α Lyræ, ε Ursæ Majoris, and ζ^1 Ursæ Majoris respectively. A least square solution gave :—

$$A = 0{\cdot}72 \pm 0{\cdot}05$$
$$\phi_1 - \phi_2 = +0{\cdot}04 \pm 0{\cdot}04$$
$$\phi_1 - \phi_3 = -0{\cdot}06 \pm 0{\cdot}04$$

The difference between this value of A and the mean value 0·32 given above is probably ascribable to the different wave-lengths employed, which is to be expected as it is known that the extinction is much greater in the violet region.

For the purpose of the small corrections to be applied to the intercomparisons of the standard stars* the following values were adopted.

	A
Up to 1928 January ..	0·72
λ 3994 — λ 5789	
Subsequent to 1928 January	0·50
λ 4139 — λ 6486	

It has been already pointed out that since the comparisons between the standard stars were taken at approximately equal altitudes, admissible errors in the adopted values are immaterial.

16. *Horizontal Reddening.*—In the comparison with the acetylene flame the use of a collimator was avoided by mounting the lamp on a roof 600 feet from the telescope.

This, however, whilst retaining the advantage of identical optical train for star and lamp, introduced an error due to atmospheric extinction in the 600 feet of air intervening.

If $\Delta\phi'$ denote the gradient for *acetylene — star* after correction, as explained in the previous section, for atmospheric reddening of the star light, and A' represents

* See p. 19.

the reddening between the telescope and the acetylene flame, the final value $\Delta\phi$ is given by

$$\Delta\phi = \Delta\phi' - A'$$

The quantity A' was determined by projecting a beam of light from a collimating telescope, mounted on a terrace immediately outside the dome, to a plane mirror mounted near the acetylene lamp on the roof, which reflected the beam into a second telescope beside the first on the terrace. An image of a light source in the focus of the first telescope was thereby formed in the focus of the second, where it was received on the slit of a spectrograph and a photograph taken.

The mirror was then brought to within a few feet of the apparatus and a second exposure made. A comparison of the two spectra gave the quantity $2A'$. Measurements were made for two groups of 8 wave-lengths each, the mean wave-lengths being λ 4457 and λ 6112.

The first collimator was a 9-inch speculum mirror of 10 feet focus, by Sir William Herschel, mounted in its original tube, used in Newtonian form. A small stop placed at the focus was illuminated by an electric lamp with diffusing screen, the voltage being controllable and kept constant during the exposures.

The second collimator (also a Herschel mirror) was similar in every essential to the first.

It was found that A' varied from night to night and was closely related to the values of the visibility which are taken as a matter of routine by the Meteorological Department of the Observatory. The visibilities are obtained by eye estimates, the farthest visible of certain selected objects (mainly groups of lights) being noted by the observer.

The following table gives the observed values of A' and the values of $1/V$ for the same nights, V being the visibility in miles. The value of A' given was usually derived from the mean of two plates.

Date	$1/V$	A'
1931 July 9..	·07	+·02
July 16	·20	+·11
October 1	·28	+·14
October 5	·28	+·17
October 7	·16	+·04
October 9	·40	+·16
October 14	·33	+·25
October 24	·43	+·15
1932 March 14	·67	+·32

The values of A' were plotted against those of $1/V$ (see Fig. 8) and a smooth curve drawn through the representative points. For the nights on which the acetylene was photographed the values of A' were read off from this curve to correspond with the visibilities observed on these nights. (The details are given on p. 31.) The mean value of A' for the series is 0·11 and it will be observed that the corresponding point on the curve is well determined by the observations. The contribution made by horizontal reddening to the final probable error may be taken as $\pm$·01.

17. *Results of Comparisons with acetylene flame.*—As has been mentioned previously, on each plate of the series was photographed the spectra of :—

1. A standard star near the zenith.
2. Two standard stars at zenith distances 50° to 60° in different azimuths (usually east and west of the meridian) from which A is determined.
3. The acetylene flame (photographed through the colour filter).
4. The photometric scale.

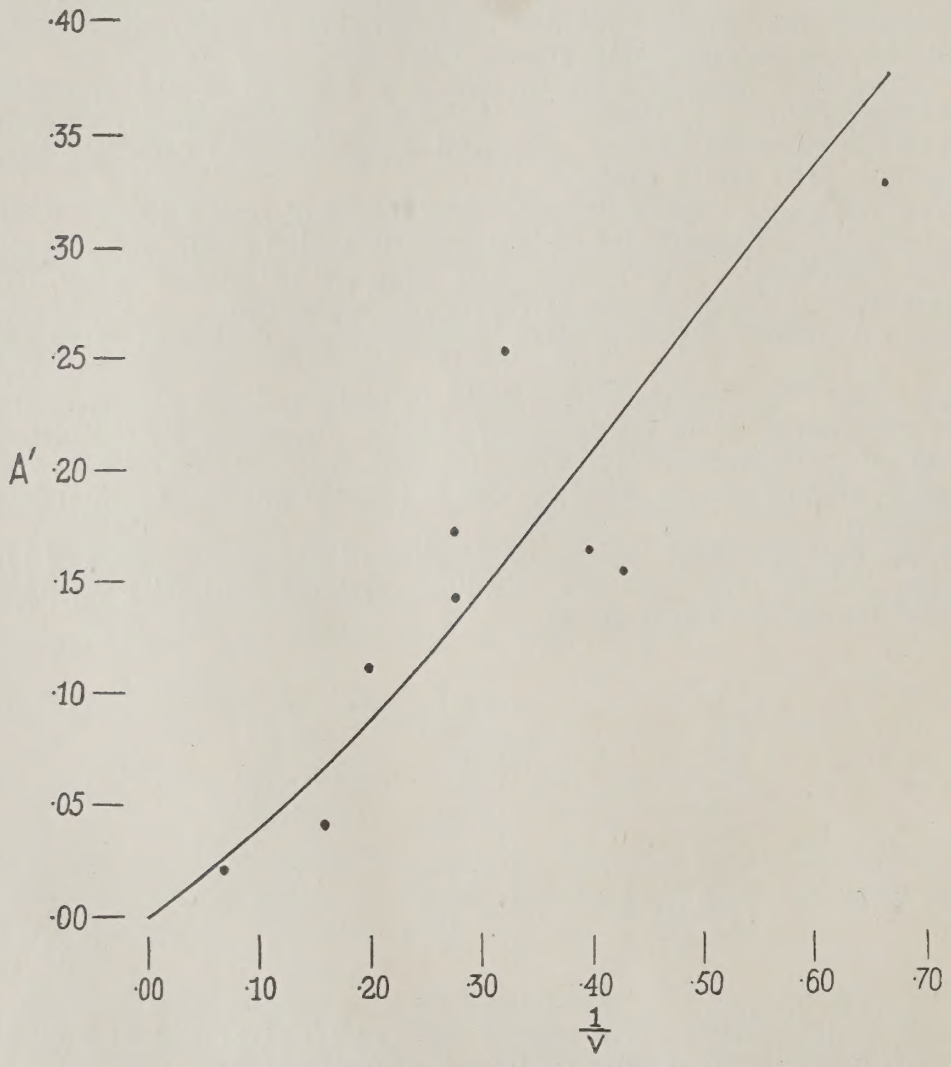

FIG. 8. HORIZONTAL REDDENING AND VISIBILITY.
A′ HORIZONTAL REDDENING FOR 600 FEET.
V VISIBILITY IN MILES.

One of the plates is reproduced in the frontispiece.

The mean values of A given for the several nights in the table on p. 26, Section 15, were applied to the results of the comparisons between the acetylene flame and the

high stars. The corrections for horizontal reddening were then applied as indicated in Section 16.

The results are set forth in detail in the following Table.

COMPARISON OF STARS WITH ACETYLENE FLAME

Star	Date		$\frac{1}{V}$	Observed $\Delta\phi$	Correction for reddening		Gradient of Star	$\phi_{acet} - \phi_0$
	Star	Acetylene			Star $A \sec z$	Acetylene A'		
	1931							
β U. Maj.	April 11	April 12	·16	+4·25	+·63	−·06	−·02	4·80
β U. Maj.	April 11	April 12	·16	+4·38	+·63	−·06	−·02	4·93
η U. Maj.	April 13	April 13	·28	+4·75	+·31	−·13	−·23	4·70
β U. Maj.	April 17	April 13	·28	+4·33	+·64	−·13	−·02	4·82
η U. Maj.	April 30	May 1	·50	+4·80	+·30	−·26	−·23	4·61
η U. Maj.	May 5	May 1	·50	+4·84	+·29	−·26	−·23	4·64
η U. Maj.	May 6	May 7	·23	+4·66	+·48	−·10	−·23	4·81
γ U. Min.	May 6	May 7	·23	+4·23	+·51	−·10	+·19	4·83
η U. Maj.	May 12	May 7	·23	+4·61	+·32	−·10	−·23	4·60
γ U. Min.	May 12	May 7	·23	+4·33	+·35	−·10	+·19	4·77
γ U. Min.	May 28	May 29	·16	+4·47	+·29	−·06	+·19	4·89
γ U. Min.	May 28	May 29	·16	+4·46	+·29	−·06	+·19	4·88
γ U. Min.	June 12	June 14	·05	+4·35	+·49	−·02	+·19	5·01
α Lyra.	June 17	June 19	·50	+4·64	−·05	−·26	·00	4·33
α Lyra.	July 3	July 4	·07	+4·44	+·37	−·03	·00	4·78
α Lyra.	July 6	July 4	·07	+4·52	+·13	−·03	·00	4·62
α Lyra.	July 11	July 14	·16	+4·48	+·10	−·06	·00	4·52
α Lyra.	July 11	July 14	·16	+4·54	+·10	−·06	·00	4·58
α Ceph.	Nov. 1	Nov. 2	·29	+4·48	+·26	−·14	+·44	5·04
α Ceph.	Nov. 1	Nov. 2	·29	+4·41	+·27	−·14	+·44	4·98
δ Cass.	Nov. 1	Nov. 2	·29	+4·69	+·26	−·14	+·25	5·06

The mean result for all the plates is as follows :—

$$\phi_A - \phi_0 = 4{\cdot}77 \pm {\cdot}03$$

where ϕ_A denotes the value of ϕ for the acetylene flame and ϕ_0 denotes the value of ϕ for the zero of the standard system.

The nominal colour temperature of the acetylene flame is 2360° K corresponding to $\phi_A = 6{\cdot}07$. If this be applied, there results :—

$$\phi_0 = 1{\cdot}30$$
$$\text{giving} \quad T_0 = 12100°$$

where T_0 is the corresponding colour temperature. But, as will appear in the next section, the acetylene burner used gave a higher colour temperature than 2360° and the value of T_0 will be correspondingly higher.

18. *Calibration of Burner.*—The nominal colour temperature for Kodak burners when set to maximum candle power (see page 21) is 2360°K. This, however, is a general result, which is not necessarily applicable to a particular burner. In order

to determine the value of T_A applicable to the Greenwich observations, the burner was sent to the National Physical Laboratory for calibration after the conclusion of the observations. It was found that the burner did in fact possess an idiosyncrasy, and gave a colour temperature some 45° higher than two other Kodak burners in the possession of the National Physical Laboratory. But in addition to this there was a variation depending on the pressure in the containing cylinder, an effect which had not been anticipated.

In the National Physical Laboratory tests, dissolved acetylene, supplied (as at Greenwich) in cylinders by Messrs. Allen Liversidge, was used. The method of purification was identical with that used at Greenwich and described on page 21. The setting screw was set to 11 revolutions below its highest position on the stem, this being the setting prescribed by Messrs. Kodak for maximum candle power, and used throughout the Greenwich observations. The pressure at the burner inlet was maintained at 9 cms. of water.

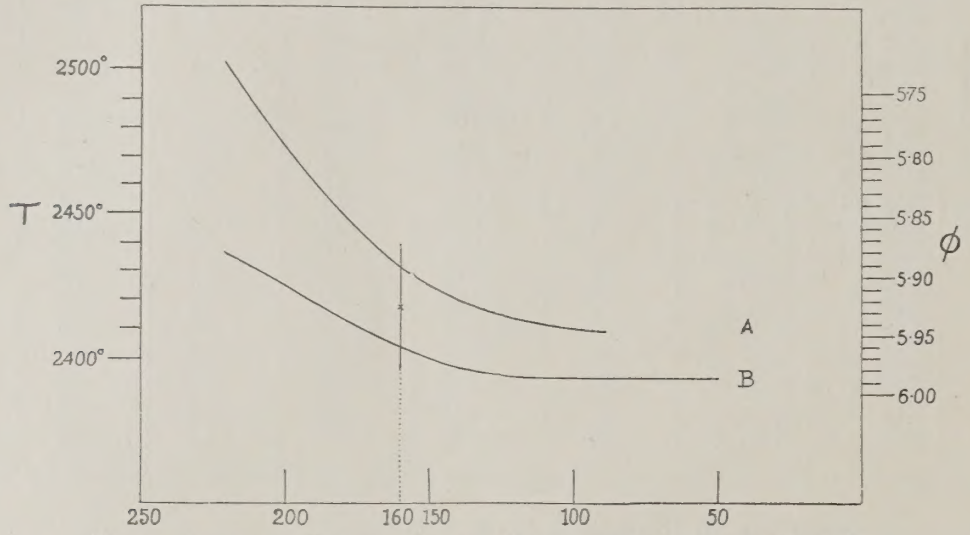

FIG. 9 ACETYLENE BURNER—COLOUR TEMPERATURE FROM TWO CYLINDERS.
CYLINDER PRESSURE IN LBS. PER SQUARE INCH.
× = Adopted Value.

It was found that the colour temperature varied with the pressure in the containing cylinder. The effect is shown for two cylinders in Fig. 9. The curve marked *B* was obtained from observations on the Greenwich burner itself. The curve marked *A* was obtained for a different cylinder, from observations on one of the National Physical Laboratory burners which had previously been found to burn at a colour temperature of 45° below the Greenwich burner. This 45° has been applied so that curve *A* refers to the Greenwich burner.

It was also found that the position of the adjusting screw corresponding to maximum candle power was at 9 revolutions instead of 11. The colour temperature for the position of maximum candle power (9 revolutions) was found to be 12° smaller than the colour temperature at the setting used at Greenwich (11 revolutions).*

* The points of maximum colour temperature and maximum candle power in the acetylene flame are different.

The variation of colour temperature with the pressure of the containing cylinder is possibly ascribable to the presence of an impurity which is given off at the higher pressures and is not eliminated by the method of purification adopted (which was designed to eliminate acetone).

The effect had not been foreseen and no records were made of the cylinder pressures on the occasions when the acetylene spectrum was photographed. Two cylinders were employed during the Greenwich series of observations. The first was in use up to and including 1931 May 29. At the commencement of the series the pressure was 180 lbs/sq. inch, the cylinder having been previously employed on experimental work. By May 29 the pressure had fallen to 120 lbs/sq. inch. The second cylinder was used for the first time on June 12, the pressure being about 200 lbs/sq. inch and at the end of the series it was 130 lbs/sq. inch.

The mean cylinder pressure for the entire series may be taken to be 160 lbs /sq. inch. The colour temperatures given by curves B and A for this pressure are 2404°K and 2432°K, the corresponding values of ϕ being 5·96 and 5·89.

The accidental errors of the acetylene and star observations are large enough to mask the variation of T_A during the life of each cylinder. A plate which had been exposed on acetylene on May 29 (1st. cylinder 120 lbs/sq. inch) was re-exposed on June 12 (new cylinder, 200 lbs/sq. inch). From this, after applying the corrections for horizontal reddening, a difference of $+ 0{\cdot}20$ in ϕ was found for May 29 *minus* June 13. As a check on this the acetylene spectra on the May 29 and June 12 plates were compared with the scale spectra (the scale lamp having been run at the same voltage on each occasion). This comparison gave $\Delta\phi = + 0{\cdot}11$ in the same sense. The mean result is $\Delta\phi = + 0{\cdot}16$, indicating that the second cylinder burnt at a colour temperature 56° higher than the first. Furthermore, previous to the series the first cylinder had been used in connection with some experimental work on the colour temperature of a carbon arc, and had replaced a previous cylinder. The discontinuity at the time of replacement was of the order of 0·2 in $\Delta\phi$ in the same sense.

These results seem to indicate that the behaviour of the Greenwich cylinders was more nearly that shown by curve A. But too much weight cannot be placed on this evidence and the mean of the two curves for a pressure of 160 lbs/sq. inch has been adopted. The values of ϕ_A from these curves for the pressure in question are 5·96 and 5·89 giving a mean of 5·93. The uncertainty can be represented by a probable error of $\pm$ ·04,

so that we now have

$$\phi_A = 5{\cdot}93 \pm {\cdot}04$$
$$\phi_A - \phi_0 = 4{\cdot}77 \pm {\cdot}03$$
$$\text{giving } \phi_0 = 1{\cdot}16 \pm {\cdot}05$$
$$\text{corresponding to } T_0 = 14300°$$

19. *Discussion of Residuals.*—It was pointed out in Section 15 that for the purpose of investigating possible departures of the energy distribution of stellar radiation from the black body law, the residuals of the derived gradients *acetylene — star* must be corrected by the residuals, *at the same wave-lengths*, of the values for atmospheric reddening after a linear gradient had been taken out. Further, as the atmosphere has entered, to a certain extent, into the acetylene (see Section 16), a further correction for this effect must be applied.

Consider a simple case in which there is photographed on one plate the spectra of—

1. A standard star P near the zenith, the zenith distance being z_1.
2. A standard star Q photographed at a zenith distance z_2 of 50° to 60°.
3. The acetylene flame F.

Let, at each wave-length λ, $R_{1\lambda}$ be the residual from the derived linear gradient for the comparison $F - P$ and let $R_{2\lambda}$ be the residual for the comparison $Q-P$.

Denote also by $R_{3\lambda}$ the corresponding residual for the horizontal reddening.

It can be assumed that any departures from the black body law will in general be similar for all the standard stars. If R_λ denote the residual at wave-length λ from the black body law for these stars we shall have

$$R_\lambda = R_{1\lambda} + R_{2\lambda} \times \frac{sec\ z_1}{sec\ z_2 - sec\ z_1} - R_{3\lambda}$$

The residuals $R_{3\lambda}$ were not measured (see page 29) and it has been assumed that they will be proportional to the corresponding residuals for atmospheric reddening at the zenith. The latter residuals are

$$\frac{R_{2\lambda}}{sec\ z_2 - sec\ z_1} = R'_{2\lambda} \text{ say,}$$

and it has been assumed that

$$R_{3\lambda} = R'_{2\lambda} \times \frac{A'}{A}$$

where as before A' and A denote the gradients for horizontal and atmospheric reddening. The mean value of A for the series is ·32 and the mean value of A' is ·11 so that

$$\frac{A'}{A} = \frac{11}{32}$$

The following table gives for the five groups the following quantities—

(1) the mean wave-length,
(2) the mean residual $R_{1\lambda}$ for acetylene *minus* zenith star for each group,
(3) The mean residual $R'_{2\lambda}$ for the atmosphere at the zenith,
and (4) the deduced values of R_λ. The mean value of $sec\ z_1$ is 1·03 and does not affect the computation to the accuracy desired.

Group	Mean λ	Mean Residual $R_{1\lambda}$ (acetylene — star)	Mean Residual $R'_{2\lambda}$ (atmosphere at zenith)	$R_\lambda = R_{1\lambda} + \frac{11}{32} R'_{2\lambda}$
		m	m	m
I	4499	+·003	—·005	—·001
II	4847	+·008	+·008	+·013
III	5307	—·003	—·001	—·004
IV	5780	—·011	—·003	—·013
V	6423	+·010	+·003	+·012

The values of R_λ are of the order of 0·01 of a magnitude and the conclusion is that there are no sensible departures from the black body law for the stars over the range of wave-length considered.

The results for the atmospheric reddening indicate that the extinctions are sensibly proportional to $1/\lambda$ over the range of wave-length considered. There is reason to believe that this will not hold for wave-lengths still further to the violet (see p. 28).

20. *Colour Temperatures and Spectral Types.*—The values of ϕ for the standard stars can now be obtained from their gradients by adding ϕ_0. That is :—

$$\phi = G + 1{\cdot}16$$

The same applies to any star whose gradient has been determined by comparison with one or more standards. The details of the observations of 37 such stars are given on pages 55 to 60. The same values of A, the coefficient of atmospheric reddening, were adopted as in the case of the standard star comparisons (see p. 28).

In the case of stars of types B and A, the spectra were measured at the same wave-lengths as for the standard stars (see Section 12, p. 19). For types F and G the measurements were made at the same eight points in the red and at six points in the blue of greater wave-length than λ4500. The wave-lengths used were as follows :—

	Blue λ		Red λ
1	4509	1	6082
2	4619	2	6215
3	4715	3	6273
4	4746	4	6318
5	4779	5	6364
6	4798	6	6395
		7	6443
		8	6486

H. H. Plaskett* has pointed out that for solar type spectra there is a tendency for the observed intensities to fall below the Planck curve for wave-lengths less than λ 4500. The same has been found to hold for the Greenwich plates. The magnitude of the effect varies with the purity of the spectrum and Plaskett suggests that it is due to absorption lines. On the other hand, when colour temperatures for these stars are derived from measures at wave-lengths exceeding λ 4500, sensibly the same results are obtained from spectra of widely different purity.

Some stars had been compared with α Cygni prior to the rejection of the latter as a standard star (see p. 20). To make use of these comparisons the gradients for α Cygni given in the last column of Table II on page 54 were plotted against the corresponding epochs. A smooth curve was then drawn through the plotted points and whenever a star had been compared with α Cygni a gradient of the latter for the date in question was read from this curve. In forming the means, half weight has been given to the α Cygni comparisons as treated in this way.

Comparisons have been made between γ Cassiopeiæ and ε Persei and between ζ Persei and ε Persei in addition to comparisons of each of these stars with standard

* *Publications Dominion Astrophysical Observatory*, Vol. 2, p. 253.

stars. For these three stars a mathematical adjustment has been made so as to give the solution of closest fit to all the observations.

Values of G, ϕ and T are given on page 61 for 61 stars, including the 25 standards. The relation of colour temperature to spectral type is exhibited in Fig. 10. It will be observed that for types B3 to F8 the representative points are

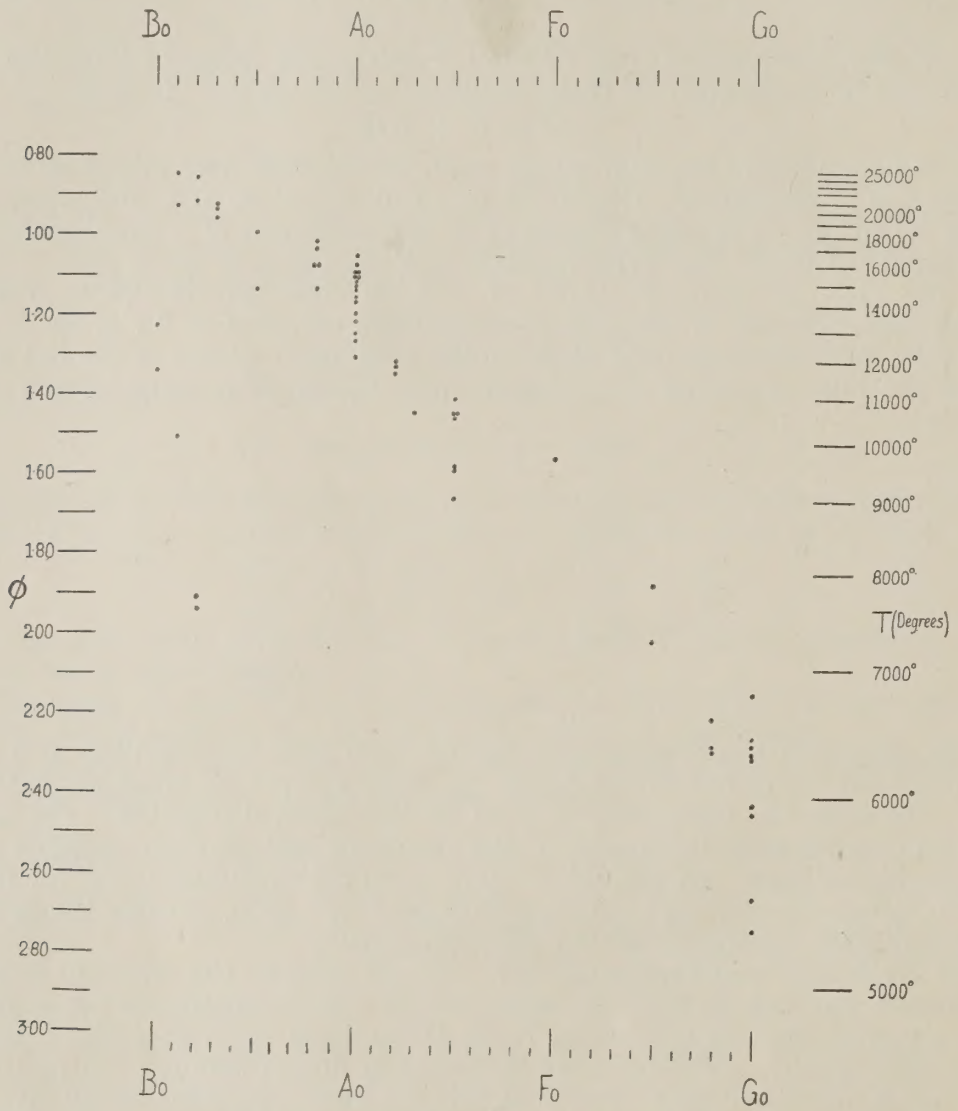

FIG. 10. COLOUR TEMPERATURES AND SPECTRAL TYPES.

grouped roughly about a straight line running across the diagram. For type G0 there is an enhanced dispersion in the colour temperatures. This is most probably to be ascribed to an absolute magnitude effect and it will be observed that the two lowest temperatures in this class are those of the giant stars Capella ($T = 5420°$) and

ε Leo ($T = 5260°$). The following table for the G0 stars is interesting. The absolute magnitudes are computed from the visual magnitudes and parallaxes given in Schlesinger's *Catalogue of Bright Stars*.

STARS OF TYPE G0

Star	Absolute magnitude	ϕ	$T°$
β Comæ	4·9	2·29	6300
β Canum Ven.	4·5	2·44	5920
ι Persei	4·1	2·27	6400
ζ Herculis	3·1	2·42	5960
Pi. 20^h332	3·1	2·14	6780
η Bootis	2·8	2·25	6460
υ Pegasi	1·3	2·30	6280
α Aurigæ	−0·6	2·65	5420
ϵ Leo	−1·5	2·73	5260

In types B0, B1, B2 there is also a very heavy dispersion in colour temperature, the values ranging from 24300° (β Cephei) to 7550° (χ^2 Orionis). The existence of a number of "yellow" stars of these types is now a well recognised but puzzling fact. The values of ϕ and T for the five stars of this class which have been observed at Greenwich are

"YELLOW" STARS TYPES B0, B1, B2.

Star	Type	ϕ	T°
γ Cassiopeiæ	B0*p*	1·23	13100
α Camelopardi	B0	1·34	11700
ζ Persei	B1	1·51	10100
9 Cephei	B2*p*	1·90	7750
χ^2 Orionis	B2*p*	1·94	7550

In the case of the observations of δ Cephei (p. 60) the phases reckoned from visual maximum are given. The observations obtained are not sufficient for the purpose of exhibiting the colour variation.

21. *Comparison with other results.*—The only previous extensive series of *absolute* observations is that carried out by Wilsing and his collaborators. The temperatures obtained at Greenwich are definitely higher than those obtained by Wilsing. Thus for type A0 Wilsing's results (as amended by Brill*) give a colour temperature of 10250° K corresponding to $\phi = 1{\cdot}49$ whereas the Greenwich observations give ϕ = about 1·20 for the same type.

H. H. Plaskett† and C. G. Abbot‡ have each determined the absolute colour temperatures of a few stars by photographic and radiometric methods respectively. For five of the stars on these two lists gradients have been determined at Greenwich

* *Astronomische Nachrichten*, Vol. 219, 356, 365, 1923.
† *Publications Dominion Astrophysical Observatory*, Vol. 2.
‡ *Astrophysical Journal*, Vol. 60, pages 87 to 107.

and the absolute observations can be utilised accordingly to derive the values of ϕ_0, the value of ϕ for the zero of the gradient system. The results are as follows :—

VALUES OF ϕ_0

(Using Temperatures determined by Plaskett and Abbott and Greenwich Gradients.)

Star	T (Plaskett)	T (Abbot)	ϕ	G (Greenwich Gradient)	$\phi_0 = \phi - G$
γ Cassiopeiæ	15000°	—	1·12	+ ·07	1·05
ϵ Persei	15000°	—	1·12	− ·23	1·35
δ Cassiopeiæ	9000°	—	1·66	+ ·25	1·41
α Aurigæ	5750°	5800°	2·51 2·49	+1·49	1·01
α Lyræ	—	14000°	1·18	·00	1·18

The mean result $\phi_0 = 1{\cdot}20$ agrees with the Greenwich value $\phi_0 = 1{\cdot}16$ within the probable errors.

The temperatures given in this volume are in substantial agreement with those given by R. A. Sampson* from relative observations made at Edinburgh. This is really to be expected as the temperature (5420°) obtained at Greenwich for Capella is in fair agreement with the value (5500°) assumed by Sampson whose temperatures are based on this assumption.

22. This investigation which began in 1926 has been carried out under the supervision of Mr. Greaves and Mr. Davidson, assisted by Mr. Martin. The work at the Equatorial has been arduous and has been shared by these three observers assisted occasionally by Messrs. Jeffries, Newton and Chamberlain. The work at the photometer was carried out by Messrs. Greaves, Davidson and Martin. Acknowledgment is due to Prof. J. S. S. Brame, of the Royal Naval College, for assistance in the setting up of the acetylene apparatus, and to the National Physical Laboratory for an extensive investigation with reference to the calibration of the Kodak burner.

1932 *April.* F. W. DYSON.

* *Monthly Notices, Royal Astronomical Society,* 1930 May.

Observations of Colour Temperatures of Stars.

NOTES

TABLE I

This Table gives the results of the intercomparison of the Standard Stars.

Each comparison is entered twice, once under each of the two stars concerned.

The approximate R. A. and Dec. are given for each star and are referred to the equinox of 1925.

The Harvard visual magnitudes and spectral types are given.

The gradients are those given by the least squares solution (*see* Section 12 of Introduction), rounded off to the second place.

TABLE II

This Table gives the results for α Cygni.

TABLE III

The results for 37 stars are given.

Comparisons with α Cygni have been treated as indicated on page 35 of the Introduction.

In the case of δ Cephei, the phases, reckoned from visual maximum, are added. They have been derived from the formula given in *B.A.A. Handbook*, 1923.

Occasionally a star was compared with more than one standard on the same night. In such cases mean results have been entered.

TABLE IV

This Table gives the collected results for Standard Stars and other stars.

TABLE V

This Table will assist the computation of T from ϕ and vice versa.

TABLE I.—OBSERVATIONS OF STANDARD STARS.

α ANDROMEDÆ

($0^h\ 4^m + 28°\ 41'$)
$2.^m15$ Aop G = −·10

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmos-pheric Reddening	Gradient of Com-parison Star	G.
	1927 Sept. 27	−·34	−·06		−·15
	Sept. 29	−·33	+·01		−·07
	Oct. 2	−·33	−·01		−·09
δ Cass.	Oct. 3	−·14	−·01	+·25	+·10
	1928 Sept. 26	−·32	−·01		−·08
	Oct. 4	−·42	·00		−·17
	1928 Oct. 25	−·36	·00		−·07
β Aris.	Oct. 30	−·34	−·01		−·06
	Nov. 15	−·27	−·04	+·29	−·02
	Nov. 19	−·28	−·02		−·01
	1928 Oct. 25	−·26	−·03		·00
β Tria.	Oct. 30	−·30	−·02		−·03
	Nov. 15	−·36	−·03	+·29	−·10
	Dec. 9	−·43	−·01		−·15
	1926 Oct. 7	−·01	−·06		−·09
η Taur.	Oct. 9	−·17	−·06		−·25
	Oct. 31	−·09	−·07	−·02	−·18
	Nov. 5	−·23	−·04		−·29
γ Orio.	1927 Jan. 26	+·07	−·10		−·27
	Jan. 27	+·16	−·15	−·24	−·23
	1931 Oct. 12	−·14	−·02		−·16
α Lyra.	Oct. 20	+·01	−·02		−·01
	Nov. 1	−·03	·00	·00	−·03
	1928 July 21	−·12	−·06		−·14
ζ Aqil.	July 29	−·14	+·02		−·08
	Aug. 8	−·11	−·02	+·04	−·09
	Aug. 9	−·08	−·04		−·08
	1929 July 17	−·42	−·02		−·02
α Aqil.	July 19	−·58	+·04		−·12
	Aug. 23	−·45	+·01	+·42	−·02
	Aug. 26	−·56	−·02		−·16
	1929 Aug. 28	−·53	−·02		−·12
α Ceph.	Sept. 26	−·50	·00		−·07
	Sept. 27	−·52	−·02	+·43	−·11
	1928 Aug. 28	−·09	+·02		−·10
	Sept. 4	−·14	+·04		−·13
α Pegs.	Sept. 7	−·18	+·04		−·17
	Sept. 22	−·05	+·04	−·03	−·04
	Sept. 26	−·03	+·02		−·04

γ PEGASI

($0^h\ 9^m + 14°\ 46'$)
$2.^m87$ B2 G = −·30

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmos-pheric Reddening	Gradient of Com-parison Star	G.
	1928 Oct. 30	−·55	·00		−·26
β Aris.	Nov. 15	−·47	−·04	+·29	−·22
	Dec. 9	−·60	−·01		−·32
	1927 Sept. 27	−·56	−·01		−·28
	Sept. 29	−·65	+·04		−·32
β Tria.	Oct. 3	−·67	+·03	+·29	−·35
	1928 Sept. 26	−·60	·00		−·31
	1929 Sept. 26	−·53	−·04		−·28
	Sept. 27	−·52	−·04		−·27
	1927 Aug. 27	−·33	−·01		−·37
α Pegs.	Sept. 24	−·23	−·01	−·03	−·27
	Sept. 26	−·24	·00		−·27
	1928 Oct. 30	−·32	·00		−·35

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

δ CASSIOPEIÆ

($1^h\ 21^m + 59°\ 51'$)
$2.^m80$ A5 G = +·25

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1927 Sept. 27	+·34	+·06		+·30
	Sept. 29	+·33	−·01		+·22
α Andr.	Oct. 2	+·33	+·01	−·10	+·24
	Oct. 3	+·14	+·01		+·05
	1928 Sept. 26	+·32	+·01		+·23
	Oct. 4	+·42	·00		+·32
	1928 Nov. 19	+·04	·00		+·33
β Tria.	Dec. 29	−·05	+·02	+·29	+·26
	1932 Jan. 21	−·15	+·02		+·16
δ Pers.	1932 Jan. 21	+·18	·00	−·16	+·02
	1929 Jan. 19	+·33	+·01		+·32
η Taur.	Feb. 3	+·20	−·01	−·02	+·17
	1932 Jan. 21	+·20	+·01		+·19
	1928 Nov. 19	+·31	−·02		+·35
β Auri.	1929 Jan. 19	+·18	−·02	+·06	+·22
	Jan. 20	+·20	+·01		+·27
	1929 Jan. 19	+·36	−·09		+·25
β U. Maj.	Feb. 3	+·39	−·08	−·02	+·29
	Mar. 1	+·29	+·03		+·30
	1928 Aug. 28	+·07	·00		+·26
γ U. Min.	Sept. 1	−·01	+·01	+·19	+·19
	Sept. 15	+·06	+·05		+·30
	Sept. 22	+·12	+·01		+·32
	Sept. 26	+·02	−·02		+·19
	1931 Oct. 12	+·47	−·02		+·45
α Lyra.	Oct. 20	+·54	−·02	·00	+·52
	Nov. 1	+·24	−·01		+·23
	1929 July 17	+·25	·00		+·29
ζ Aqil.	July 19	+·25	+·04	+·04	+·33
	Aug. 23	+·15	·00		+·19
	Aug. 26	+·17	·00		+·21
	1929 July 15	−·32	·00		+·10
α Aqil.	July 17	−·19	·00	+·42	+·23
	July 18	−·18	+·01		+·25
	July 19	−·29	·00		+·13
	1929 Aug. 28	−·26	·00		+·17
α Ceph.	Sept. 20	−·23	−·01	+·43	+·19
	Sept. 25	−·22	·00		+·21
	Sept. 26	−·05	·00		+·38

β ARIETIS

($1^h\ 50^m + 20°\ 27'$)
$2.^m72$ A5 G = +·29

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1928 Oct. 25	+·36	·00		+·26
α Andr.	Oct. 30	+·34	+·01	−·10	+·25
	Nov. 15	+·27	+·04		+·21
	Nov. 19	+·28	+·02		+·20
	1928 Oct. 30	+·55	·00		+·25
γ Pegs.	Nov. 15	+·47	+·04	−·30	+·21
	Dec. 9	+·60	+·01		+·31
	1926 Oct. 9	+·60	−·01		+·43
δ Pers.	Oct. 10	+·60	−·07	−·16	+·37
	Oct. 31	+·52	−·01		+·35
	Nov. 5	+·37	−·01		+·20
	1926 Nov. 14	+·37	−·01		+·34
η Taur.	1927 Jan. 26	+·52	−·02	−·02	+·48
	Jan. 27	+·36	−·06		+·28
	1928 Nov. 15	+·30	−·04		+·24
	1928 Jan. 10	+·58	−·07		+·27
γ Orio.	1929 Dec. 2	+·46	+·04	−·24	+·26
	1930 Jan. 18	+·53	+·06		+·35
	Jan. 19	+·40	+·06		+·22

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

β TRIANGULI

($2^h\ 5^m + 34°\ 38'$)
$3^{\cdot m}08$ A5 G = +·29

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
α Andr.	1928 Oct. 25	+·26	+·03		+·19
	Oct. 30	+·30	+·02	−·10	+·22
	Nov. 15	+·36	+·03		+·29
	Dec. 9	+·43	+·01		+·34
γ Pegs.	1927 Sept. 27	+·56	+·01		+·27
	Sept. 29	+·65	−·04		+·31
	Oct. 3	+·67	−·03	−·30	+·34
	1928 Sept. 26	+·60	·00		+·30
	1929 Sept. 26	+·53	+·04		+·27
	Sept. 27	+·52	+·04		+·26
δ Cass.	1928 Nov. 19	−·04	·00		+·21
	Dec. 29	+·05	−·02	+·25	+·28
	1932 Jan. 21	+·15	−·02		+·38
δ Pers.	1928 Dec. 29	+·42	−·01	−·16	+·25
	1932 Jan. 21	+·47	−·01		+·30
η Taur.	1932 Jan. 13	+·28	+·02	−·02	+·28
	Jan. 21	+·18	+·02		+·18
γ Orio.	1931 Dec. 7	+·59	+·05		+·40
	1932 Jan. 21	+·53	+·04	−·24	+·33
	Feb. 6	+·49	+·04		+·29
β Taur.	1929 Jan. 19	+·42	−·02	−·14	+·26
	Jan. 20	+·49	−·02		+·33
β Auri.	1928 Nov. 19	+·18	−·01		+·23
	1929 Jan. 19	+·24	−·01	+·06	+·29
	Jan. 20	+·21	·00		+·27
β C. Min.	1930 Jan. 19	+·34	−·02		+·30
	Jan. 25	+·38	−·02	−·02	+·34
	1931 Dec. 7	+·46	−·02		+·42

δ PERSEI

($3^h\ 38^m + 47°\ 33'$)
$3^{\cdot m}10$ B5 G = −·16

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
δ Cass.	1932 Jan. 21	−·18	·00	+·25	+·07
β Aris.	1926 Oct. 9	−·60	+·01		−·30
	Oct. 10	−·60	+·07	+·29	−·24
	Oct. 31	−·52	+·01		−·22
	Nov. 5	−·37	+·01		−·07
β Tria.	1928 Dec. 29	−·42	+·01	+·29	−·12
	1932 Jan. 21	−·47	+·01		−·17
β Taur.	1929 Jan. 20	−·04	+·02		−·16
	Feb. 3	+·06	+·02	−·14	−·06
	1932 Feb. 6	+·02	+·01		−·11
β Auri.	1929 Jan. 19	−·19	−·02		−·15
	Jan. 20	−·18	−·01	+·06	−·13
	Jan. 26	−·26	·00		−·20
	1932 Jan. 21	−·15	−·01		−·10
β C. Min.	1930 Feb. 8	−·10	+·04		−·08
	Mar. 1	−·04	+·04	−·02	−·02
	1932 Feb. 29	−·32	·00		−·34
	Mar. 1	−·17	+·02		−·17
β U. Maj.	1932 Jan. 30	−·14	+·05		−·11
	Feb. 6	−·31	·00	−·02	−·33
	Feb. 29	−·11	−·02		−·15
	Mar. 1	−·14	·00		−·16
α Ceph.	1927 Sept. 29	−·49	−·06		−·12
	Dec. 6	−·77	+·01		−·33
	Dec. 16	−·68	−·01	+·43	−·26
	1928 Oct. 18	−·65	+·04		−·18
	Oct. 25	−·57	+·02		−·12

TABLE I.—OBSERVATIONS OF STANDARD STARS.—*continued.*

η TAURI

$(3^h\ 43^m + 23°\ 52')$
$2.^m96$ B5p G = −·02

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1926 Oct. 7	+·01	+·06		−·03
α Andr.	Oct. 9	+·17	+·06	−·10	+·13
	Oct. 31	+·09	+·07		+·06
	Nov. 5	+·23	+·04		+·17
	1929 Jan. 19	−·33	−·01		−·09
δ Cass.	Feb. 3	−·20	+·01	+·25	+·06
	1932 Jan. 21	−·20	−·01		+·04
	1926 Nov. 14	−·37	+·01		−·07
β Aris.	1927 Jan. 26	−·52	+·02	+·29	−·21
	Jan. 27	−·36	+·06		−·01
	1928 Nov. 15	−·30	+·04		+·03
β Tria.	1932 Jan. 13	−·28	−·02	+·29	−·01
	Jan. 21	−·18	−·02		+·09
	1928 Jan. 24	+·15	−·11		−·20
γ Orio.	1930 Jan. 25	+·27	+·04	−·24	+·07
	Feb. 17	+·14	+·03		−·07
	Feb. 20	+·16	+·06		−·02
	1927 Dec. 28	+·12	−·02		−·04
β Taur.	1928 Jan. 13	+·04	−·01	−·14	−·11
	Jan. 15	+·10	−·03		−·07
	1932 Jan. 21	+·08	−·01		−·07
β Auri.	1932 Jan. 21	·00	−·01	+·06	+·05
	1931 Dec. 7	·00	·00		−·02
β C. Min.	1932 Jan. 21	−·05	+·02	−·02	−·05
	Feb. 6	+·12	+·02		+·12
α Gemi	1929 Jan. 19	−·08	−·04	+·11	−·01
	1932 Feb. 6	−·05	−·01		+·05
	1927 Jan. 10	−·07	−·04		−·13
β U. Maj.	Jan. 25	+·01	−·08	−·02	−·09
	Jan. 26	−·01	−·06		−·09
	Jan. 27	+·02	−·02		−·02

γ ORIONIS

$(5^h\ 21^m + 6°\ 17')$
$1.^m70$ B2 G = −·24

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
α Andr.	1927 Jan. 26	−·07	+·10	−·10	−·07
	Jan. 27	−·16	+·15		−·11
	1928 Jan. 10	−·58	+·07		−·22
β Aris.	1929 Dec. 2	−·46	−·04	+·29	−·21
	1930 Jan. 18	−·53	−·06		−·30
	Jan. 19	−·40	−·06		−·17
	1931 Dec. 7	−·59	−·05		−·35
β Tria.	1932 Jan. 21	−·53	−·04	+·29	−·28
	Feb. 6	−·49	−·04		−·24
	1928 Jan. 24	−·15	+·11		−·06
η Taur.	1930 Jan. 25	−·27	−·04	−·02	−·33
	Feb. 17	−·14	−·03		−·19
	Feb. 20	−·16	−·06		−·24
	1930 Jan. 19	−·15	−·06		−·23
β C. Min.	Jan. 25	−·16	−·07	−·02	−·25
	Feb. 20	−·16	−·04		−·22
	1932 Jan. 21	−·35	·00		−·37
	1929 Nov. 26	−·28	−·06		−·23
α Gemi.	Dec. 2	−·40	−·05	+·11	−·34
	1930 Jan. 18	−·34	−·06		−·29
	Jan. 19	−·32	−·06		−·27
	1926 Jan. 9	−·49	+·06		−·45
β U. Maj.	Jan. 11	−·03	+·08	−·02	+·03
	Jan. 12	−·48	+·12		−·38
	Jan. 20	−·25	+·08		−·19

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

β TAURI

($5^h\ 22^m + 28°\ 33'$)
$1.^m78$ B8 G = −·14

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
β Tria.	1929 Jan. 19	−·42	+·02	+·29	−·11
	Jan. 20	−·49	+·02		−·18
	1929 Jan. 20	+·04	−·02		−·14
δ Pers.	Feb. 3	−·06	−·02	−·16	−·24
	1932 Feb. 6	−·02	−·01		−·19
	1927 Dec. 28	−·12	+·02		−·12
η Taur.	1928 Jan. 13	−·04	+·01	−·02	−·05
	Jan. 15	−·10	+·03		−·09
	1932 Jan. 21	−·08	+·01		−·09
β Auri.	1929 Jan. 20	−·14	−·04	+·06	−·12
	Feb. 3	−·25	−·03		−·22
	1930 Mar. 1	−·10	+·03		−·09
β C. Min.	1932 Feb. 29	−·11	·00	−·02	−·13
	Mar. 1	−·26	·00		−·28
	Mar. 2	−·11	+·01		−·12
	1928 Jan. 19	−·29	+·03		−·15
α Gemi.	Jan. 22	−·26	−·01	+·11	−·16
	Jan. 24	−·29	+·01		−·17
	1929 Jan. 19	−·30	−·02		−·21
	1929 Jan. 19	−·11	−·01		−·14
β U. Maj.	Feb. 3	−·07	−·06	−·02	−·15
	1932 Jan. 30	−·12	−·01		−·15
	Feb. 6	+·12	−·02		+·08

β AURIGÆ

($5^h\ 54^m + 44°\ 56'$)
$2.^m07$ Aop G = +·06

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1928 Nov. 19	−·31	+·02		−·04
δ Cass.	1929 Jan. 19	−·18	+·02	+·25	+·09
	Jan. 20	−·20	−·01		+·04
	1928 Nov. 19	−·18	+·01		+·12
β Tria.	1929 Jan. 19	−·24	+·01	+·29	+·06
	Jan. 20	−·21	·00		+·08
	1929 Jan. 19	+·19	+·02		+·05
δ Pers.	Jan. 20	+·18	+·01	−·16	+·03
	Jan. 26	+·26	·00		+·10
	1932 Jan. 21	+·15	+·01		·00
η Taur.	1932 Jan. 21	·00	+·01	−·02	−·01
β Taur.	1929 Jan. 20	+·14	+·04	−·14	+·04
	Feb. 3	+·25	+·03		+·14
	1928 Jan. 19	−·01	+·02		+·12
α Gemi.	Jan. 24	−·05	−·03	+·11	+·03
	1929 Jan. 19	−·03	−·02		+·06
	Mar. 1	−·04	+·03		+·12
	1929 Jan. 20	+·19	+·02		+·19
β U. Maj.	Feb. 3	+·03	·00	−·02	+·01
	Mar. 2	+·07	+·01		+·06
	Mar. 4	+·12	−·01		+·09
	1929 Feb. 3	−·19	·00		·00
γ U. Min.	Feb. 28	−·04	−·06	+·19	+·09
	Mar. 2	−·20	+·02		+·01
	Mar. 4	−·14	−·01		+·04

TABLE I.—OBSERVATIONS OF STANDARD STARS.—*continued.*

β CANIS MINORIS

$(7^h\ 23^m + 8°\ 26')$
$3.^m09$ B8 G = −·02

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1930 Jan. 19	−·34	+·02		−·03
β Tria.	Jan. 25	−·38	+·02	+·29	−·07
	1931 Dec. 7	−·46	+·02		−·15
	1930 Feb. 8	+·10	−·04		−·10
δ Pers.	Mar. 1	+·04	−·04	−·16	−·16
	1932 Feb. 29	+·32	·00		+·16
	Mar. 1	+·17	−·02		−·01
	1931 Dec. 7	·00	·00		−·02
η Taur.	1932 Jan. 21	+·05	−·02	−·02	+·01
	Feb. 6	−·12	−·02		−·16
	1930 Jan. 19	+·15	+·06		−·03
γ Orio.	Jan. 25	+·16	+·07	−·24	−·01
	Feb. 20	+·16	+·04		−·04
	1932 Jan. 21	+·35	·00		+·11
	1930 Mar. 1	+·10	−·03		−·07
β Taur.	1932 Feb. 29	+·11	·00	−·14	−·03
	Mar. 1	+·26	·00		+·12
	Mar. 2	+·11	−·01		−·04
	1930 Feb. 17	−·05	−·02		−·15
	Mar. 1	+·09	−·01		·00
α Leon.	1932 Feb. 29	+·09	−·03	−·08	−·02
	Mar. 1	+·30	+·01		+·23
	Mar. 2	+·10	+·04		+·06
δ Leon.	1930 Mar. 1	−·29	−·04	+·29	−·04

α GEMINORUM (MEAN OF COMPONENTS)

$(7^h\ 30^m + 32°\ 3')$
$1.^m58$ A0 G = +·11

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
η Taur.	1929 Jan. 19	+·08	+·04	−·02	+·10
	1932 Feb. 6	+·05	+·01		+·04
	1929 Nov. 26	+·28	+·06		+·10
γ Orio.	Dec. 2	+·40	+·05	−·24	+·21
	1930 Jan. 18	+·34	+·06		+·16
	Jan. 19	+·32	+·06		+·14
	1928 Jan. 19	+·29	−·03		+·12
β Taur.	Jan. 22	+·26	+·01	−·14	+·13
	Jan. 24	+·29	−·01		+·14
	1929 Jan. 19	+·30	+·02		+·18
	1928 Jan. 19	+·01	−·02		+·05
β Auri.	Jan. 24	+·05	+·03	+·06	+·14
	1929 Jan. 19	+·03	+·02		+·11
	Mar. 1	+·04	−·03		+·07
	1928 Apr. 8	+·19	−·01		+·10
α Leon.	1929 Jan. 19	+·01	+·10	−·08	+·03
	Feb. 3	+·18	+·01		+·11
	Feb. 28	+·11	+·06		+·09
	1929 Jan. 19	+·08	+·02		+·08
β U. Maj.	Feb. 3	+·20	−·06	−·02	+·12
	Feb. 28	+·09	−·02		+·05
	Mar. 2	+·09	−·03		+·04
	1929 Mar. 2	−·21	−·04		+·04
δ Leon.	Mar. 4	−·16	−·04	+·29	+·09
	Mar. 7	−·23	+ 04		+·10
	Mar. 9	−·08	+·02		+·23
	1926 Mar. 9	+·24	+·07		+·08
η U. Maj.	Mar. 10	+·38	+·08	−·23	+·23
	Mar. 13	+·46	−·06		+·17
	Mar. 15	+·24	−·08		−·07

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

α LEONIS

(10h 4m + 12° 20′)
1·m34 B8 G = −·08

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1930 Feb. 17	+·05	+·02		+·05
β C. Min.	Mar. 1	−·09	+·01	−·02	−·10
	1932 Feb. 29	−·09	+·03		−·08
	Mar. 1	−·30	−·01		−·33
	Mar. 2	−·10	−·04		−·16
	1928 Apr. 8	−·19	+·01		−·07
α Gemi.	1929 Jan. 19	−·01	−·10	+·11	·00
	Feb. 3	−·18	−·01		−·08
	Feb. 28	−·11	−·06		−·06
	1928 Jan. 24	−·38	−·04		−·13
	1929 Jan. 19	−·33	·00		−·04
δ Leon.	Feb. 28	−·24	−·02	+·29	+·03
	Mar. 2	−·28	−·02		−·01
	Mar. 4	−·35	−·02		−·08
	1929 Feb. 3	·00	−·07		−·13
α C. Ven.	Feb. 28	−·07	+·01	−·06	−·12
	Mar. 2	−·08	·00		−·14
	Mar. 4	−·05	−·02		−·13
	1929 Mar. 27	+·22	−·03		−·04
η U. Maj.	Mar. 28	+·18	−·02	−·23	−·07
	Apr. 6	+·17	−·05		−·11

β URSÆ MAJORIS

(10h 57m + 56° 47′)
2·44 Ao G = −·02

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1929 Jan. 19	−·36	+·09		−·02
δ Cass.	Feb. 3	−·39	+·08	+·25	−·06
	Mar. 1	−·29	−·03		−·07
	1932 Jan. 30	+·14	−·05		−·07
δ Pers.	Feb. 6	+·31	·00	−·16	+·15
	Feb. 29	+·11	+·02		−·03
	Mar. 1	+·14	·00		−·02
	1927 Jan. 10	+·07	+·04		+·09
η Taur.	Jan. 25	−·01	+·08	−·02	+·05
	Jan. 26	+·01	+·06		+·05
	Jan. 27	−·02	+·02		−·02
	1926 Jan. 9	+·49	−·06		+·19
γ Orio.	Jan. 11	+·03	−·08	−·24	−·29
	Jan. 12	+·48	−·12		+·12
	Jan. 20	+·25	−·08		−·07
	1929 Jan. 19	+·11	+·01		−·02
β Taur.	Feb. 3	+·07	+·06	−·14	−·01
	1932 Jan. 30	+·12	+·01		−·01
	Feb. 6	−·12	+·02		−·24
	1929 Jan. 20	−·19	−·02		−·15
β Auri.	Feb. 3	−·03	·00	+·06	+·03
	Mar. 2	−·07	−·01		−·02
	Mar. 4	−·12	+·01		−·05
	1929 Jan. 19	−·08	−·02		+·01
α Gemi.	Feb. 3	−·20	+·06	+·11	−·03
	Feb. 28	−·09	+·02		+·04
	Mar. 2	−·09	+·03		+·05
	1929 Mar. 2	+·14	·00		+·08
α C. Ven.	Mar. 4	−·11	+·02	−·06	−·15
	Mar. 7	+·04	+·02		·00
	Mar. 9	+·13	+·01		+·08
	1926 Apr. 10	+·14	−·04		−·13
	Apr. 12	+·13	−·01		−·11
η U. Maj.	Apr. 13	+·12	−·01	−·23	−·12
	Apr. 15	+·25	−·01		+·01
	1929 Mar. 2	+·25	·00		+·02
	Mar. 4	+·20	+·02		−·01
	1928 May 5	−·33	−·03		−·17
γ U. Min.	May 8	−·16	·00	+·19	+·03
	May 14	−·17	−·03		−·01
	1929 Mar. 9	−·21	·00		−·02
	1929 Apr. 30	−·40	−·04		−·01
α Ceph.	May 3	−·51	+·01	+·43	−·07
	May 10	−·47	+·02		−·02
	May 30	−·38	+·04		+·09

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

δ LEONIS

(11h 10m + 20° 56′)
2·m58 A3 G = +·29

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
β C. Min.	1930 Mar. 1	+·29	+·04	−·02	+·31
	1929 Mar. 2	+·21	+·04		+·36
α Gemi.	Mar. 4	+·16	+·04	+·11	+·31
	Mar. 7	+·23	−·04		+·30
	Mar. 9	+·08	−·02		+·17
	1928 Jan. 24	+·38	+·04		+·34
	1929 Jan. 19	+·33	·00		+·25
α Leon.	Feb. 28	+·24	+·02	−·08	+·18
	Mar. 2	+·28	+·02		+·22
	Mar. 4	+·35	+·02		+·29
	1929 Mar. 2	+·45	−·04		+·35
α C. Ven.	Mar. 4	+·36	−·03	−·06	+·27
	Mar. 7	+·25	−·01		+·18
	Mar. 9	+·41	−·02		+·33
	1926 Mar. 13	+·58	−·08		+·27
η U. Maj.	Mar. 15	+·72	−·06	−·23	+·43
	Apr. 12	+·61	−·06		+·32
	Apr. 13	+·67	−·06		+·38
	1929 Mar. 7	+·05	·00		+·24
γ U. Min.	Mar. 9	+·07	+·01	+·19	+·27
	Apr. 6	+·04	−·02		+·21
	May 2	+·31	−·05		+·45
	1929 Mar. 9	+·28	−·04		+·25
α Cor. B.	Apr. 6	+·27	−·05	+·01	+·23
	Apr. 30	+·42	−·03		+·40
	May 2	+·30	·00		+·31

α CANUM VENATICORUM (BRIGHTER COMPONENT)

(12h 53m + 38° 43′)
2·m90 A0p G = −·06

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1929 Feb. 3	·00	+·07		−·01
α Leon.	Feb. 28	+·07	−·01	−·08	−·02
	Mar. 2	+·08	·00		·00
	Mar. 4	+·05	+·02		−·01
	1929 Mar. 2	−·14	·00		−·16
β U. Maj.	Mar. 4	+·11	−·02	−·02	+·07
	Mar. 7	−·04	−·02		−·08
	Mar. 9	−·13	−·01		−·16
	1929 Mar. 2	−·45	+·04		−·12
δ Leon.	Mar. 4	−·36	+·03	+·29	−·04
	Mar. 7	−·25	+·01		+·05
	Mar. 9	−·41	+·02		−·10
	1928 May 8	+·26	−·04		−·01
η U. Maj.	May 14	+·12	−·03	−·23	−·14
	1929 Mar. 2	+·20	·00		−·03
	Mar. 4	+·22	+·01		·00
	1929 Mar. 18	−·32	+·04		−·09
γ U. Min.	Mar. 27	−·39	+·03	+·19	−·17
	Mar. 28	−·21	+·02		·00
	Apr. 30	−·16	·00		+·03
	1929 Apr. 6	−·10	+·06		−·03
α Cor. B.	Apr. 30	−·11	+·01	+·01	−·09
	May 2	−·16	+·02		−·13
	May 3	−·09	+·04		−·04
	1928 May 9	−·08	−·02		−·10
	May 18	−·13	·00		−·13
α Lyra.	May 25	+·10	−·04	·00	+·06
	1929 Apr. 30	−·07	+·01		−·06
	May 3	−·13	+·04		−·09

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

η URSÆ MAJORIS

$(13^h\ 45^m + 49°\ 41')$
$1.^m91$ B3 G = −·23

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1926 Mar. 9	−·24	−·07		−·20
α Gemi.	Mar. 10	−·38	−·08	+·11	−·35
	Mar. 13	−·46	+·06		−·29
	Mar. 15	−·24	+·08		−·05
	1929 Mar. 27	−·22	+·03		−·27
α Leon.	Mar. 28	−·18	+·02	−·08	−·24
	Apr. 6	−·17	+·05		−·20
	1926 Apr. 10	−·14	+·04		−·12
	Apr. 12	−·13	+·01		−·14
β U. Maj.	Apr. 13	−·12	+·01	−·02	−·13
	Apr. 15	−·25	+·01		−·26
	1929 Mar. 2	−·25	·00		−·27
	Mar. 4	−·20	−·02		−·24
	1926 Mar. 13	−·58	+·08		−·21
δ Leon.	Mar. 15	−·72	+·06	+·29	−·37
	Apr. 12	−·61	+·06		−·26
	Apr. 13	−·67	+·06		−·32
	1928 May 8	−·26	+·04		−·28
α C. Ven.	May 14	−·12	+·03	−·06	−·15
	1929 Mar. 2	−·20	·00		−·26
	Mar. 4	−·22	−·01		−·29
	1929 Apr. 30	−·37	+·01		−·17
γ U. Min.	May 3	−·45	+·02	+·19	−·24
	May 10	−·39	+·02		−·18
	May 21	−·35	+·02		−·14
	1926 May 6	−·33	+·04		−·28
α Cor. B.	May 15	−·39	+·04	+·01	−·34
	May 16	−·48	+·04		−·43
	May 31	−·13	+·04		−·08
	1929 June 9	−·42	+·04		−·08
α Ophi.	June 10	−·60	+·04	+·30	−·26
	June 18	−·68	+·04		−·34
	June 24	−·56	+·03		−·23

γ URSÆ MINORIS

$(15^h\ 21^m + 72°\ 6')$
$3.^m14$ A2 G = +·19

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1928 Aug. 28	−·07	·00		+·18
	Sept. 1	+·01	−·01		+·25
δ Cass.	Sept. 15	−·06	−·05	+·25	+·14
	Sept. 22	−·12	−·01		+·12
	Sept. 26	−·02	+·02		+·25
	1929 Feb. 3	+·19	·00		+·25
β Auri.	Feb. 28	+·04	+·06	+·06	+·16
	Mar. 2	+·20	−·02		+·24
	Mar. 4	+·14	+·01		+·21
	1928 May 5	+·33	+·03		+·34
β U. Maj.	May 8	+·16	·00	−·02	+·14
	May 14	+·17	+·03		+·18
	1929 Mar. 9	+·21	·00		+·19
	1929 Mar. 7	−·05	·00		+·24
δ Leon.	Mar. 9	−·07	−·01	+·29	+·21
	Apr. 6	−·04	+·02		+·27
	May 2	−·31	+·05		+·03
	1929 Mar. 18	+·32	−·04		+·22
α C. Ven.	Mar. 27	+·39	−·03	−·06	+·30
	Mar. 28	+·21	−·02		+·13
	Apr. 30	+·16	·00		+·10
	1929 Apr. 30	+·37	−·01		+·13
η U. Maj.	May 3	+·45	−·02	−·23	+·20
	May 10	+·39	−·02		+·14
	May 21	+·35	−·02		+·10
	1929 Apr. 6	+·23	+·04		+·28
α Cor. B.	Apr. 30	+·20	+·02	+·01	+·23
	May 2	+·15	+·02		+·18
	May 3	+·19	+·03		+·23
	1928 May 9	+·12	+·04		+·16
α Lyra.	May 18	+·11	+·04	·00	+·15
	May 25	+·13	+·02		+·15
	June 1	+·19	+·04		+·23
	1929 June 29	+·06	+·06		+·16
	July 5	+·06	+·05		+·15
ζ Aqil.	July 11	+·09	+·04	+·04	+·17
	July 15	+·25	+·04		+·33
	July 17	+·07	+·05		+·16
	1929 June 24	−·26	−·02		+·15
α Ceph.	June 29	−·23	·00	+·43	+·20
	July 5	−·17	−·02		+·24
	July 11	−·19	−·02		+·22

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

α CORONÆ BOREALIS

($15^h\ 32^m + 26°\ 58'$)
2^m31 A0 G = +·01

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1929 Mar. 9	−·28	+·04		+·05
δ Leon.	Apr. 6	−·27	+·05	+·29	+·07
	Apr. 30	−·42	+·03		−·10
	May 2	−·30	·00		−·01
	1929 Apr. 6	+·10	−·06		−·02
α C. Ven.	Apr. 30	+·11	−·01	−·06	+·04
	May 2	+·16	−·02		+·08
	May 3	+·09	−·04		−·01
	1926 May 6	+·33	−·04		+·06
η U. Maj.	May 15	+·39	−·04	−·23	+·12
	May 16	+·48	−·04		+·21
	May 31	+·13	−·04		−·14
	1929 Apr. 6	−·23	−·04		−·08
γ U. Min.	Apr. 30	−·20	−·02	+·19	−·03
	May 2	−·15	−·02		+·02
	May 3	−·19	−·03		−·03
	1929 June 6	−·30	+·03		+·03
α Ophi.	June 9	−·36	+·04	+·30	−·02
	June 10	−·30	+·03		+·03
	June 17	−·31	+·03		+·02
	1928 May 9	−·05	+·02		−·03
	1929 Apr. 30	+·02	·00		+·02
α Lyra.	May 10	−·12	+·01	·00	−·11
	May 30	+·03	·00		+·03
	June 6	−·11	−·01		−·12
	1929 June 9	−·06	+·01		−·01
ζ Aqil.	June 10	−·08	+·04	+·04	·00
	June 17	−·01	+·01		+·04
	June 18	−·06	+·06		+·04
	1929 June 17	−·44	−·01		−·02
α Ceph.	June 18	−·42	+·02	+·43	+·03
	June 24	−·42	−·01		·00

α OPHIUCHI

($17^h\ 31^m + 12°\ 37'$)
2^m14 A5 G = +·30

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1929 June 9	+·42	−·04		+·15
η U. Maj.	June 10	+·60	−·04	−·23	+·33
	June 18	+·68	−·04		+·41
	June 24	+·56	−·03		+·30
	1929 June 6	+·30	−·03		+·28
α Cor. B.	June 9	+·36	−·04	+·01	+·33
	June 10	+·30	−·03		+·28
	June 17	+·31	−·03		+·29
	1929 June 17	+·24	−·02		+·26
ζ Aqil.	June 18	+·16	+·01	+·04	+·21
	June 24	+·29	·00		+·33
	June 29	+·32	+·02		+·38
	1928 July 11	−·21	+·02		+·23
α Aqil.	July 12	−·09	+·01	+·42	+·34
	July 13	−·25	+·04		+·21
	July 21	−·11	+·03		+·34
	1929 May 10	−·08	−·01		+·34
α Ceph.	June 6	−·10	−·03	+·43	+·30
	June 9	+·01	−·04		+·40
	June 10	−·07	−·03		+·33

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

α LYRÆ (VEGA)

(18h 34m + 38° 43′)
0·m14 A0 G = ·00

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1931 Oct. 12	+·14	+·02		+·06
α Andr.	Oct. 20	−·01	+·02	−·10	−·09
	Nov. 1	+·03	·00		−·07
	1931 Oct. 12	−·47	+·02		−·20
δ Cass.	Oct. 20	−·54	+·02	+·25	−·27
	Nov. 1	−·24	+·01		+·02
	1928 May 9	+·08	+·02		+·04
	May 18	+·13	·00		+·07
α C. Ven.	May 25	−·10	+·04	−·06	−·12
	1929 Apr. 30	+·07	−·01		·00
	May 3	+·13	−·04		+·03
	1928 May 9	−·12	−·04		+·03
γ U. Min.	May 18	−·11	−·04	+·19	+·04
	May 25	−·13	−·02		+·04
	June 1	−·19	−·04		−·04
	1928 May 9	+·05	−·02		+·04
	1929 Apr. 30	−·02	·00		−·01
α Cor. B.	May 10	+·12	−·01	+·01	+·12
	May 30	−·03	·00		−·02
	June 6	+·11	+·01		+·13
	1928 July 7	−·38	+·03		+·08
	July 9	−·46	+·02		−·01
α Ceph.	July 11	−·53	·00	+·43	−·10
	July 12	−·49	·00		−·06
	July 17	−·50	−·02		−·09
	July 21	−·43	+·01		+·01
	1929 Aug. 23	+·03	+·10		+·10
	Aug. 26	+·09	·00		+·06
α Pegs.	Aug. 28	+·14	+·02	−·03	+·13
	Sept. 20	−·09	+·04		−·08
	Sept. 25	+·04	+·02		+·03

ζ AQUILÆ

(19h 2m + 13° 45′)
3·m02 A0 G = +·04

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1928 July 21	+·12	+·06		+·08
α Andr.	July 29	+·14	−·02	−·10	+·02
	Aug. 8	+·11	+·02		+·03
	Aug. 9	+·08	+·04		+·02
	1929 July 17	−·25	·00		·00
δ Cass.	July 19	−·25	−·04	+·25	−·04
	Aug. 23	−·15	·00		+·10
	Aug. 26	−·17	·00		+·08
	1929 June 29	−·06	−·06		+·07
	July 5	−·06	−·05		+·08
γ U. Min.	July 11	−·09	−·04	+·19	+·06
	July 15	−·25	−·04		−·10
	July 17	−·07	−·05		+·07
	1929 June 9	+·06	−·01		+·06
α Cor. B.	June 10	+·08	−·04	+·01	+·05
	June 17	+·01	−·01		+·01
	June 18	+·06	−·06		+·01
	1929 June 17	−·24	+·02		+·08
α Ophi.	June 18	−·16	−·01	+·30	+·13
	June 24	−·29	·00		+·01
	June 29	−·32	−·02		−·04
	1928 Aug. 8	−·36	+·02		+·08
	Aug. 28	−·37	·00		+·05
α Aqil.	Sept. 1	−·37	+·02	+·42	+·07
	Sept. 4	−·47	·00		−·05
	Sept. 7	−·46	+·02		−·02
	1929 Aug. 23	+·07	−·02		+·02
α Pegs.	Aug. 26	+·09	−·02	−·03	+·04
	Aug. 28	+·11	·00		+·08
	Aug. 30	+·10	+·04		+·11

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

α AQUILÆ

($19^h\ 47^m + 8°\ 40'$)
$0.^m89$ A5 G = +·42

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1929 July 17	+·42	+·02		+·34
α Andr.	July 19	+·58	−·04	−·10	+·44
	Aug. 23	+·45	−·01		+·34
	Aug. 26	+·56	+·02		+·48
	1929 July 15	+·32	·00		+·57
δ Cass.	July 17	+·19	·00	+·25	+·44
	July 18	+·18	−·01		+·42
	July 19	+·29	·00		+·54
	1928 July 11	+·21	−·02		+·49
α Ophi.	July 12	+·09	−·01	+·30	+·38
	July 13	+·25	−·04		+·51
	July 21	+·11	−·03		+·38
	1928 Aug. 8	+·36	−·02		+·38
	Aug. 28	+·37	·00		+·41
ζ Aqil.	Sept. 1	+·37	−·02	+·04	+·39
	Sept. 4	+·47	·00		+·51
	Sept. 7	+·46	−·02		+·48
	1927 Aug. 25	+·31	−·06		+·22
α Pegs.	Sept. 22	+·50	−·04	−·03	+·43
	Sept. 26	+·45	−·06		+·36
	Oct. 3	+·45	−·06		+·36

α CEPHEI

($21^h\ 17^m + 62°\ 16'$)
$2.^m60$ A5 G = +·43

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1929 Aug. 28	+·53	+·02		+·45
α Andr.	Sept. 26	+·50	·00	−·10	+·40
	Sept. 27	+·52	+·02		+·44
	1929 Aug. 28	+·26	·00		+·51
δ Cass.	Sept. 20	+·23	+·01	+·25	+·49
	Sept. 25	+·22	·00		+·47
	Sept. 26	+·05	·00		+·30
	1927 Sept. 29	+·49	+·06		+·39
	Dec. 6	+·77	−·01		+·60
δ Pers.	Dec. 16	+·68	+·01	−·16	+·53
	1928 Oct. 18	+·65	−·04		+·45
	Oct. 25	+·57	−·02		+·39
	1929 Apr. 30	+·40	+·04		+·42
β U. Maj.	May 3	+·51	−·01	−·02	+·48
	May 10	+·47	−·02		+·43
	May 30	+·38	−·04		+·32
	1929 June 24	+·26	+·02		+·47
γ U. Min.	June 29	+·23	·00	+·19	+·42
	July 5	+·17	+·02		+·38
	July 11	+·19	+·02		+·40
	1929 June 17	+·44	+·01		+·46
α Cor. B.	June 18	+·42	−·02	+·01	+·41
	June 24	+·42	+·01		+·44
	1929 May 10	+·08	+·01		+·39
α Ophi.	June 6	+·10	+·03	+·30	+·43
	June 9	−·01	+·04		+·33
	June 10	+·07	+·03		+·40
	1928 July 7	+·38	−·03		+·35
	July 9	+·46	−·02		+·44
α Lyra.	July 11	+·53	·00	·00	+·53
	July 12	+·49	·00		+·49
	July 17	+·50	+·02		+·52
	July 21	+·43	−·01		+·42

TABLE I.—OBSERVATIONS OF STANDARD STARS—*continued.*

α PEGASI

($23^h\ 1^m + 14°\ 48'$)
$2.^m57$ Ao G = −·03

Comparison Star	Date	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Comparison Star	G.
	1928 Aug. 28	+·09	−·02		−·03
	Sept. 4	+·14	−·04		·00
α Andr.	Sept. 7	+·18	−·04	−·10	+·04
	Sept. 22	+·05	−·04		−·09
	Sept. 26	+·03	−·02		−·09
	1927 Aug. 27	+·33	+·01		+·04
γ Pegs.	Sept. 24	+·23	+·01	−·30	−·06
	Sept. 26	+·24	·00		−·06
	1928 Oct. 30	+·32	·00		+·02
	1929 Aug. 23	−·03	−·10		−·13
	Aug. 26	−·09	·00		−·09
α Lyra.	Aug. 28	−·14	−·02	·00	−·16
	Sept. 20	+·09	−·04		+·05
	Sept. 25	−·04	−·02		−·06
	1929 Aug. 23	−·07	+·02		−·01
ζ Aqil.	Aug. 26	−·09	+·02	+·04	−·03
	Aug. 28	−·11	·00		−·07
	Aug. 30	−·10	−·04		−·10
	1927 Aug. 25	−·31	+·06		+·17
α Aqil.	Sept. 22	−·50	+·04	+·42	−·04
	Sept. 26	−·45	+·06		+·03
	Oct. 3	−·45	+·06		+·03

TABLE II

α CYGNI

($20^h\ 39^m + 45°\ 1'$)
$1.^m3$ A2p

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.	Mean Epoch
1926 Sept. 30	δ Pers.	+·09	−·04	−·16	−·11	
Oct. 2	δ Pers.	+·37	·00	−·16	+·21	+·04
Oct. 7	δ Pers.	+·25	−·07	−·16	+·02	1926·78
Nov. 12	δ Pers.	+·20	−·01	−·16	+·03	
1927 Aug. 25	α Ceph.	−·36	+·01	+·43	+·08	
Sept. 22	α Ceph.	−·15	·00	+·43	+·28	+·17
Sept. 24	α Ceph.	−·18	−·01	+·43	+·24	1927·71
Sept. 26	α Ceph.	−·33	−·01	+·43	+·09	
1928 May 18	α Ophi.	−·43	+·04	+·30	−·09	
May 25	α Ophi.	−·08	+·05	+·30	+·27	
June 11	α Ophi.	−·42	+·06	+·30	−·06	+·20
July 11	α Lyra.	+·38	·00	·00	+·38	1928·48
July 12	α Lyra.	+·30	·00	·00	+·30	
July 17	α Lyra.	+·39	+·03	·00	+·42	
Aug. 4	α Ceph.	−·28	·00	+·43	+·15	
Sept. 26	δ Cass.	+·03	−·01	+·25	+·27	
Oct. 4	δ Cass.	+·04	−·01	+·25	+·28	
Oct. 18	α Pegs.	+·30	+·09	−·03	+·36	
Oct. 24	α Pegs.	+·33	+·05	−·03	+·35	+·32
Oct. 25	α Pegs., α Andr., δ Cass.	+·26	−·01	+·04	+·29	1928·79
Oct. 30	α Pegs., δ Cass.	+·22	+·02	+·11	+·35	
1929 May 10	α Ophi.	+·02	+·02	+·30	+·34	
June 6	α Ophi.	+·06	+·04	+·30	+·40	+·41
June 24	γ U. Min.	+·20	+·01	+·19	+·40	1929·44
June 29	γ U. Min.	+·31	−·01	+·19	+·49	
July 5	γ U. Min.	+·28	+·01	+·19	+·48	
July 11	γ U. Min.	+·23	+·01	+·19	+·43	+·42
Sept. 26	β Tria., γ Pegs.	+·36	+·01	·00	+·37	1929·62
Sept. 27	β Tria., γ Pegs.	+·37	+·02	·00	+·39	
1930 June 24	α Ceph.	−·05	−·01	+·43	+·37	+·27
June 25	α Ceph.	−·16	−·01	+·43	+·26	1930·49
July 5	α Ceph.	−·25	+·01	+·43	+·19	

TABLE III.—GRADIENTS FROM COMPARISONS WITH STANDARD STARS.

β CASSIOPEIÆ

(0h 5m + 58° 44′)
2·m42 F5

Date	Standard Star	Observed Difference of Gradient	Correction for Atmos-pheric Reddening	Gradient of Standard Star	G.
1929 Aug. 26	α Ceph.	+·15	+·01	+·43	+·59
Aug. 28	α Ceph.	+·31	+·01	+·43	+·75
Sept. 20	α Ceph.	+·33	+·01	+·43	+·77
Sept. 25	α Ceph.	+·23	+·01	+·43	+·67
Sept. 26	α Cygn.	+·22	·00	+·42	+·64*
Sept. 27	α Cygn.	+·13	+·01	+·42	+·56*
Nov. 23	δ Cass.	+·53	·00	+·25	+·78
Nov. 24	β Tria.	+·43	+·01	+·29	+·73
Nov. 26	β Tria.	+·45	·00	+·29	+·74
Dec. 2	β Tria.	+·48	·00	+·29	+·77
				Mean	+·71

* Half weight. *See* page 35.

γ CASSIOPEIÆ

(0h 52m + 60° 19′)
2·m25 Bop

Date	Standard Star	Observed Difference of Gradient	Correction for Atmos-pheric Reddening	Gradient of Standard Star	G.
1926 May 15	α Aqil.	−·51	·00	+·42	−·09
May 16	α Aqil.	−·43	·00	+·42	−·01
May 31	α Aqil.	−·37	−·04	+·42	+·01
Oct. 7	ε Pers. †	+·23	+·04	−·23	+·04
Oct. 9	ε Pers. †	+·34	+·03	−·23	+·14
Oct. 31	ε Pers. †	+·49	+·05	−·23	+·31
Nov. 5	ε Pers. †	+·18	−·04	−·23	−·09
1927 Jan. 10	η Taur.	+·25	+·01	−·02	+·24
Jan. 25	η U. Maj. } η Taur. }	+·12	+·03	−·12	+·03
Jan. 26	η U. Maj.	+·18	+·16	−·23	+·11
Jan. 27	η U. Maj. } η Taur. }	+·12	+·06	−·12	+·06
				Mean	+·07

† *See* page 35.

α URSÆ MINORIS (POLARIS)

(1h 34m + 88° 54′)
2·m12 F8

Date	Standard Star	Observed Difference of Gradient	Correction for Atmos-pheric Reddening	Gradient of Standard Star	G.
1928 June 1	α Ophi.	+0·66	+·01	+·30	+0·97
June 11	α Ophi.	+0·50	+·01	+·30	+0·81
July 21	δ Cass.	+0·75	−·01	+·25	+0·99
Aug. 8	δ Cass.	+0·87	−·03	+·25	+1·09
1930 June 25	η U. Maj.	+1·49	+·01	−·23	+1·27
Sept. 24	δ Cass.	+0·89	−·04	+·25	+1·10
				Mean	+1·04

ε CASSIOPEIÆ

(1h 49m + 63° 18′)
3·m44 B3

Date	Standard Star	Observed Difference of Gradient	Correction for Atmos-pheric Reddening	Gradient of Standard Star	G.
1928 Aug. 28	δ Cass.	−·46	·00	+·25	−·21
Sept. 1	δ Cass.	−·38	−·01	+·25	−·14
Sept. 4	δ Cass. } α Andr. }	−·28	−·01	+·07	−·22
Sept. 7	δ Cass. } α Andr. }	−·22	−·01	+·07	−·16
Sept. 22	α Andr.	−·23	·00	−·10	−·33
Sept. 26	α Andr.	−·15	+·01	−·10	−·24
				Mean	−·22

β PERSEI

(3h 3m + 40° 40′)
2·m3—3·m5 B8

Date	Standard Star	Observed Difference of Gradient	Correction for Atmos-pheric Reddening	Gradient of Standard Star	G.
1926 Sept. 30	α Andr.	+·01	·00	−·10	−·09
Oct. 2	α Andr.	+·02	−·01	−·10	−·09
Oct. 7	α Andr.	+·06	+·03	−·10	−·01
Oct. 9	α Andr.	−·06	+·02	−·10	−·14
1927 Nov. 25	β Tria.	−·57	+·01	+·29	−·27
Dec. 28	β Tria.	−·22	+·02	+·29	+·09
1928 Jan. 13	β Tria.	−·39	+·02	+·29	−·08
				Mean	−·08

ι PERSEI

(3h 4m + 49° 20′)
4·m17 Go

Date	Standard Star	Observed Difference of Gradient	Correction for Atmos-pheric Reddening	Gradient of Standard Star	G.
1928 Oct. 25	β Tria.	+0·74	+·01	+·29	+1·04
Oct. 30	β Tria.	+0·89	+·01	+·29	+1·19
Nov. 15	β Tria.	+0·81	+·01	+·29	+1·11
1930 Jan. 19	β Auri.	+0·92	−·01	+·06	+0·97
Feb. 17	β C. Min.	+1·52	+·02	−·02	(+1·52)*
Mar. 1	δ Pers.	+1·39	−·01	−·16	+1·22
				Mean	+1·11

* Not included in the mean.

TABLE III.—GRADIENTS FROM COMPARISONS WITH STANDARD STARS—*continued.*

ζ PERSEI

($3^h\ 49^m + 31°\ 40'$)
$2.^m91$ B1

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1926 Oct. 31	β Aris.	−·06	+·03	+·29	+·26
Nov. 5	β Aris.	−·05	+·01	+·29	+·25
Nov. 12	β Aris.	+·01	+·01	+·29	+·31
Nov. 14	β Aris.	+·06	+·01	+·29	+·36
1927 Oct. 22	ϵ Pers. †	+·59	+·01	−·23	+·37
Nov. 25	ϵ Pers. †	+·70	·00	−·23	+·47
Dec. 28	β Tria.	+·13	+·01	+·29	+·43
1928 Jan. 10	β Tria.	+·07	·00	+·29	+·36
Jan. 13	β Tria.	+·10	−·01	+·29	+·38
				Mean	+·35

† *See* page 35.

ϵ PERSEI

($3^h\ 53^m + 39°\ 48'$)
$2.^m96$ B1

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1926 Oct. 7	γ Cass. †	−·23	−·04	+·07	−·20
Oct. 9	γ Cass. †	−·34	−·04	+·07	−·31
Oct. 31	γ Cass. †	−·49	+·05	+·07	−·37
Nov. 5	γ Cass. †	−·18	+·04	+·07	−·07
1927 Oct. 22	ζ Pers. †	−·59	−·01	+·35	−·25
Nov. 25	ζ Pers. †	−·70	·00	+·35	−·35
Dec. 28	β Auri.	−·23	−·01	+·06	−·18
1928 Jan. 13	β Auri.	−·37	−·01	+·06	−·32
Jan. 19	β Auri.	−·16	−·01	+·06	−·11
Dec. 29	δ Pers.	+·01	−·01	−·16	−·16
				Mean	−·23

† *See* page 35.

α (9) CAMELOPARDI

($4^h\ 47^m + 66°\ 13'$)
$4.^m38$ Bo

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Sept. 26	β Tria.	−·05	−·02	+·29	+·22
Oct. 4	β Tria.	−·12	−·02	+·29	+·15
Oct. 25	β Tria.	−·29	−·02	+·29	−·02
Oct. 30	β Tria.	−·06	−·03	+·29	+·20
1929 Nov. 26	δ Cass.	−·01	·00	+·25	+·24
Dec. 19	δ Cass.	−·02	+·01	+·25	+·24
1930 Jan. 19	β Auri.	+·15	−·01	+·06	+·20
Jan. 25	β Auri.	+·15	−·02	+·06	+·19
				Mean	+·18

η AURIGÆ

($5^h\ 1^m + 41°\ 8'$)
$3.^m28$ B3

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Oct. 30	β Aris.	−·42	+·01	+·29	−·12
Nov. 15	η Taur.	−·19	+·03	−·02	−·18
Nov. 19	β Auri.	−·30	+·01	+·06	−·23
1931 Dec. 7	δ Pers.	−·11	·00	−·16	−·27
				Mean	−·20

α AURIGÆ (CAPELLA)

($5^h\ 11^m + 45°\ 55'$)
$0.^m21$ Go

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Nov. 19	β Tria.	+1·34	+·02	+·29	+1·65
Dec. 29	β Tria.	+1·31	−·01	+·29	+1·59
1929 Jan. 19	β Auri.	+1·29	+·03	+·06	+1·38
Jan. 20	β Tria.	+1·03	+·05	+·29	+1·37
1930 Jan. 25	β Auri.	+1·49	·00	+·06	+1·55
Feb. 17	α Gemi.	+1·47	·00	+·11	+1·58
Mar. 1	γ U. Min.	+1·11	+·03	+·19	+1·33
				Mean	+1·49

θ AURIGÆ

($5^h\ 55^m + 37°\ 13'$)
$2.^m71$ Aop

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Jan. 19	α Gemi.	−·23	+·04	+·11	−·08
Jan. 24	α Gemi.	−·22	+·04	+·11	−·07
1930 Jan. 25	β Auri.	−·11	−·01	+·06	−·06
Feb. 17	α Gemi.	−·11	·00	+·11	·00
1931 Dec. 7	β Auri.	−·15	−·01	+·06	−·10
				Mean	−·06

χ^2 ORIONIS

($5^h\ 59^m + 20°\ 8'$)
$4.^m71$ B2p

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1929 Jan. 19	β Taur.	+·96	−·05	−·14	+·77
Feb. 3	β Taur.	+·91	+·01	−·14	+·78
				Mean	+·78

TABLE III.—GRADIENTS FROM COMPARISONS WITH STANDARD STARS—*continued.*

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
γ GEMINORUM ($6^h\ 33^m + 16°\ 28'$) $1.^m93$ Ao					
1927 Jan. 10	β U. Maj.	+·20	−·01	−·02	+·17
Jan. 25	β U. Maj.	+·13	−·01	−·02	+·10
Jan. 27	β U. Maj.	+·20	·00	−·02	+·18
1929 Dec. 2	γ Orio.	+·35	+·06	−·24	+·17
1931 Dec. 7	β Tria.	−·19	+·03	+·29	+·13
				Mean	+·15
ι URSÆ MAJORIS ($8^h\ 54^m + 48°\ 20'$) $3.^m12$ A5					
1930 Mar. 24	α C. Ven.	+·56	+·01	−·06	+·51
Mar. 29	α C. Ven.	+·55	−·01	−·06	+·48
Apr. 2	α C. Ven.	+·62	+·03	−·06	+·59
Apr. 10	η U. Maj.	+·68	−·02	−·23	+·43
				Mean	+·50
θ URSÆ MAJORIS ($9^h\ 28^m + 52°\ 1'$) $3.^m26$ F8p					
1929 Apr. 6	γ U. Min.	+0·77	·00	+·19	+0·96
1930 Mar. 29	γ U. Min.	+1·00	−·01	+·19	+1·18
Apr. 2	γ U. Min.	+0·92	+·02	+·19	+1·13
Apr. 10	α C. Ven.	+1·27	−·01	−·06	+1·20
				Mean	+1·12
ε LEONIS ($9^h\ 42^m + 24°\ 7'$) $3.^m12$ Gop					
1929 Mar. 7	δ Leon.	+1·19	−·01	+·29	+1·47
Mar. 9	α Leon.	+1·48	+·06	−·08	+1·46
Mar. 27	δ Leon.	+1·13	+·02	+·29	+1·44
Mar. 28	δ Leon.	+1·25	+·01	+·29	+1·55
Apr. 6	δ Leon.	+1·56	·00	+·29	+1·85
1930 Mar. 24	α C. Ven.	+1·70	−·03	−·06	+1·61
Mar. 29	α C. Ven.	+1·73	−·04	−·06	+1·63
Apr. 2	α C. Ven.	+2·04	−·02	−·06	(+1·96)*
				Mean	+1·57

* Not included in mean.

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
θ LEONIS ($11^h\ 10^m + 15°\ 50'$) $3.^m41$ Ao					
1929 Mar. 18	α Leon.	+·20	+·01	−·08	+·13
Apr. 6	α Leon.	+·14	+·03	−·08	+·09
1930 Mar. 24	α Leon.	+·16	+·03	−·08	+·11
Apr. 2	α Leon.	+·09	+·03	−·08	+·04
				Mean	+·09
β LEONIS ($11^h\ 45^m + 14°\ 59'$) $2.^m23$ A2					
1928 Apr. 8	α Gemi.	−·11	+·02	+·11	+·02
May 5	δ Leon.	−·04	·00	+·29	+·25
May 8	δ Leon.	+·02	+·01	+·29	+·32
May 14	δ Leon.	−·05	·00	+·29	+·24
1929 Mar. 7	α Leon.	+·23	+·02	−·08	+·17
Mar. 9	δ Leon.	−·02	−·04	+·29	+·23
Mar. 18	α Leon.	+·16	+·01	−·08	+·09
Mar. 27	α Leon.	+·26	−·01	−·08	+·17
Mar. 28	α Leon.	+·17	−·01	−·08	+·08
				Mean	+·17
γ URSÆ MAJORIS ($11^h\ 50^m + 54°\ 7'$) $2.^m54$ Ao					
1928 Mar. 28	β U. Maj.	−·18	·00	−·02	−·20
Apr. 4	β U. Maj.	−·17	·00	−·02	−·19
Apr. 8	β U. Maj.	·00	·00	−·02	−·02
May 5	γ U. Min.	−·27	·00	+·19	−·08
May 8	α C. Ven.	+·07	·00	−·06	+·01
May 14	ζ U. Maj.	+·23	−·03	−·23	−·03
May 18	α Ophi.	−·48	·00	+·30	−·18
June 1	α Ophi.	−·20	−·04	+·30	+·06
June 11	α Ophi.	−·35	−·03	+·30	−·08
1929 May 2	α C. Ven.	+·16	·00	−·06	+·10
May 3	α C. Ven.	+·18	−·01	−·06	+·11
				Mean	−·05

TABLE III.—GRADIENTS FROM COMPARISONS WITH STANDARD STARS—*continued.*

β CANUM VENATICORUM

(12h 30m + 41° 46′)
4·m32 Go

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1929 Apr. 6	η U. Maj.	+1·30	·00	−·23	+1·07
1930 Mar. 24	β U. Maj.	+1·27	−·01	−·02	+1·24
Mar. 29	β U. Maj.	+1·58	·00	−·02	+1·56
Apr. 2	β U. Maj.	+1·29	−·01	−·02	+1·26
				Mean	+1·28

ε URSÆ MAJORIS

(12h 51m + 56° 22′)
1·m68 Aop

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1926 Mar. 13	η U. Maj.	+·32	−·01	−·23	+·08
Apr. 10	η U. Maj.	+·24	−·01	−·23	·00
Apr. 12	η U. Maj.	+·16	−·01	−·23	−·08
Apr. 13	η U. Maj.	+·33	−·01	−·23	+·09
Apr. 15	η U. Maj.	+·07	−·01	−·23	−·17
1928 Mar. 28	β U. Maj.	·00	−·02	−·02	−·04
Apr. 4	β U. Maj.	−·16	−·01	−·02	−·19
May 5	γ U. Min.	−·27	+·02	+·19	−·06
May 14	η U. Maj.	+·16	−·01	−·23	−·08
				Mean	−·05

β COMÆ

(13h 8m + 28° 15′)
4·m32 Go

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1929 Mar. 7	α C. Ven.	+1·18	−·03	−·06	+1·09
Mar. 9	α C. Ven.	+1·29	−·03	−·06	+1·20
Mar. 18	α C. Ven.	+1·41	−·06	−·06	+1·29
Mar. 27	δ Leon.	+0·50	−·01	+·29	(+0·78)*
Mar. 28	δ Leon.	+0·86	−·02	+·29	+1·13
Apr. 6	δ Leon.	+0·75	·00	+·29	+1·04
Apr. 30	γ U. Min.	+0·96	−·01	+·19	+1·14
May 2	β U. Maj.	+1·02	+·01	−·02	+1·01
				Mean	+1·13

* Not included in mean.

ζ URSÆ MAJORIS

(13h 21m + 55° 19′)
2·m40 A2p

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1926 Apr. 12	η U. Maj.	+·34	·00	−·23	+·11
Apr. 16	η U. Maj.	+·42	+·01	−·23	+·20
May 3	η U. Maj.	+·36	·00	−·23	+·13
May 6	η U. Maj.	+·47	·00	−·23	+·24
May 15	η U. Maj.	+·35	·00	−·23	+·12
				Mean	+·16

η BOÖTIS

(13h 51m + 18° 46′)
2·m80 Go

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Mar. 28	α Leon.	+1·13	+·04	−·08	+1·09
May 8	γ U. Min.	+0·91	−·04	+·19	+1·06
May 9	α Lyra.	+1·03	·00	·00	+1·03
May 14	γ U. Min.	+0·80	−·05	+·19	+0·94
May 18	α Lyra. / α Ophi.	+1·03	+·03	+·15	+1·21
May 25	α Lyra. / α Ophi.	+1·03	−·06	+·15	+1·12
June 1	α Ophi.	+0·83	−·06	+·30	+1·07
June 11	α Ophi.	+0·93	−·05	+·30	+1·18
				Mean	+1·09

γ BOÖTIS

(14h 29m + 38° 38′)
3·m00 Fo

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1929 May 3	η U. Maj.	+·59	·00	−·23	+·36
May 10	η U. Maj.	+·51	−·01	−·23	+·27
May 30	α Cor. B.	+·30	+·02	+·01	+·33
June 6	α Cor. B.	+·35	+·02	+·01	+·38
June 9	α Cor. B.	+·36	+·01	+·01	+·38
1930 Mar. 29	β U. Maj.	+·44	·00	−·02	+·42
Apr. 2	β U. Maj.	+·47	−·03	−·02	+·42
Apr. 30	α C. Ven.	+·65	+·01	−·06	+·60
				Mean	+·40

TABLE III.—GRADIENTS FROM COMPARISONS WITH STANDARD STARS—*continued.*

ζ HERCULIS

(16h 38m + 31° 44′)
3·m00 Go

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 May 9	α Cor. B.	+1·15	·00	+·01	+1·16
May 18	α Cor. B.	+1·30	·00	+·01	+1·31
May 25	α Cor. B.	+1·35	+·01	+·01	+1·37
June 1	α Lyra.	+1·35	−·02	·00	+1·33
July 13	α Lyra.	+1·29	−·02	·00	+1·27
July 17	α Lyra.	+1·24	−·02	·00	+1·22
July 29	α Lyra.	+1·19	−·04	·00	+1·15
				Mean	+1·26

γ LYRÆ

(18h 56m + 32° 35′)
3·m30 Aop

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1929 May 30	α Ceph.	−·33	+·03	+·43	+·13
June 9	α Lyra.	−·29	−·02	·00	−·31
June 10	α Lyra.	−·01	−·03	·00	−·04
July 15	α Lyra.	+·02	−·02	·00	·00
July 17	α Lyra.	+·06	−·02	·00	+·04
				Mean	−·04

δ CYGNI

(19h 43m + 44° 57′)
2·m98 Ao

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 July 17	α Cygn.	−·31	·00	+·24	−·07*
July 21	α Cygn.	−·35	·00	+·24	−·11*
July 29	α Cygn.	−·37	·00	+·24	−·13*
Aug. 4	α Cygn.	−·35	+·02	+·24	−·09*
Aug. 8	α Cygn.	−·35	·00	+·24	−·11*
Aug. 9	α Cygn.	−·36	·00	+·24	−·12*
1929 July 15	α Lyra.	−·08	+·02	·00	−·06
July 17	α Lyra.	−·06	+·01	·00	−·05
July 18	α Lyra.	+·03	+·01	·00	+·04
July 19	α Lyra.	−·17	+·01	·00	−·16
Sept. 2	α Ceph.	−·54	·00	+·43	−·11
				Mean	−·08

* Half weight. *See* page 35.

γ CYGNI

(20h 20m + 40° 1′)
2·m32 F8p

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Aug. 14	α Cygn.	+·76	·00	+·26	+1·02*
Aug. 27	α Cygn.	+·68	−·01	+·26	+0·93*
Aug. 28	α Cygn.	+·82	·00	+·26	+1·08*
Sept. 22	α Cygn.	+·92	·00	+·26	+1·18*
Sept. 26	α Cygn.	+·72	−·01	+·26	+0·97*
Sept. 30	α Ceph.	+·69	−·02	+·43	+1·10
Oct. 4	α Ceph.	+·85	−·01	+·43	+1·27
Oct. 25	α Ceph.	+·74	−·02	+·43	+1·15
				Mean	+1·11

* Half weight. *See* page 35.

β DELPHINI

(20h 34m + 14° 20′)
3·m72 F5

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Aug. 14	ζ Aqil.	+0·84	+·02	+·04	+0·90
Aug. 28	α Pegs.	+0·86	+·02	−·03	+·085
Sept. 4	α Pegs.	+1·04	−·04	−·03	+0·97
Sept. 7	α Pegs.	+0·77	−·02	−·03	+0·72
Sept. 22	ζ Aqil. / α Pegs.	+0·84	−·01	·00	+0·83
Sept. 26	ζ Aqil. / α Pegs.	+0·82	+·02	·00	+0·84
				Mean	+0·85

PIAZZI 20h 332

(20h 44m + 57° 19′)
4·m63 Go

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Sept. 30	α Ceph.	+0·35	−·01	+·43	+0·77
Oct. 4	α Ceph.	+0·83	·00	+·43	+1·26
Oct. 5	α Ceph.	+0·38	·00	+·43	+0·81
Oct. 25	α Ceph.	+0·56	·00	+·43	+0·99
1929 July 18	α Lyra.	+1·00	·00	·00	+1·00
July 19	α Lyra.	+0·93	+·01	·00	+0·94
Sept. 25	α Cygn.	+0·64	·00	+·42	+1·06*
Sept. 26	α Cygn.	+0·64	·00	+·42	+1·06*
				Mean	+0·98

* Half weight. *See* page 35.

TABLE. III—GRADIENTS FROM COMPARISONS WITH STANDARD STARS—*continued.*

β CEPHEI
(21h 28m + 70° 14′)
3·m32 B1

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 July 29	α Ceph.	−·73	−·02	+·43	−·32
Aug. 4	α Ceph.	−·85	−·02	+·43	−·44
Sept. 30	α Ceph.	−·64	−·02	+·43	−·23
Oct. 4	α Ceph.	−·73	−·02	+·43	−·32
Oct. 5	α Ceph.	−·59	−·02	+·43	−·18
Oct. 31	α Cygn.	−·63	+·01	+·28	−·34*
Nov. 15	α Cygn.	−·65	·00	+·28	−·37*
1929 June 6	α Cygn.	−·82	·00	+·40	−·36*
Aug. 28	α Lyra.	−·36	+·01	·00	−·35
Aug. 30	α Lyra.	−·40	·00	·00	−·40
Sept. 2	α Lyra.	−·33	·00	·00	−·33
Sept. 26	δ Cass.	−·48	·00	+·25	−·23
Sept. 27	δ Cass.	−·51	·00	+·25	−·26
				Mean	−·31

* Half weight. *See* page 35.

9 CEPHEI
(21h 36m + 61° 45′)
4·m87 B2p

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 July 9	α Ceph.	+·37	·00	+·43	+·80
July 13	α Ceph.	+·24	+·01	+·43	+·68
July 17	α Ceph.	+·26	·00	+·43	+·69
July 29	α Ceph.	+·32	·00	+·43	+·75
1929 Sept. 25	α Cygn.	+·41	−·01	+·42	+·82*
Sept. 26	α Cygn.	+·37	·00	+·42	+·79*
Sept. 27	α Cygn.	+·31	−·01	+·42	+·72*
				Mean	+·74

* Half weight. *See* page 35.

δ CEPHEI
(22h 26m + 58° 2′)
3·m6—4·m1 F2—G2

Date (G.M.A.T.)	Standard Star	Observed Difference of Gradient	Corrn. for Atmospheric Reddening	Gr'd'nt. of Standard Star	G.	Phase from Vis. Max.
1929 Aug. 26·51	α Ceph.	+ ·96	+·02	+·43	+1·41	205°
Aug. 28·50	α Ceph.	+ ·18	+·02	+·43	+0·63	339°
Sept. 20·44	α Ceph.	+ ·60	+·02	+·43	+1·05	78°
Sept. 25·43	α Ceph.	+ ·63	+·02	+·43	+1·08	53°
1930 June 24·49	α Ceph.	+1·02	−·06	+·43	+1·39	304°
June 25·48	α Ceph.	+ ·76	−·06	+·43	+1·13	10°
July 5·52	α Ceph.	+ ·74	−·03	+·43	+1·14	323°
Sept. 24·38	α Ceph.	+ ·52	·00	+·43	+0·95	348°

ζ PEGASI
(22h 38m + 10° 26′)
3·m61 B8

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Sept. 4	ζ Aqil.	−·19	+·04	+·04	−·11
Sept. 7	ζ Aqil.	−·10	+·03	+·04	−·03
Sept. 14	α Aqil.	−·60	·00	+·42	−·18
Sept. 22	α Aqil.	−·67	+·02	+·42	−·23
Sept. 26	α Aqil.	−·50	−·01	+·42	−·09
Sept. 30	α Aqil.	−·53	·00	+·42	−·11
1929 Aug. 28	ζ Aqil.	−·10	−·05	+·04	−·11
Aug. 30	ζ Aqil.	−·06	−·08	+·04	−·10
				Mean	−·12

υ PEGASI
(23h 22m + 22° 59′)
4·m57 G0

Date	Standard Star	Observed Difference of Gradient	Correction for Atmospheric Reddening	Gradient of Standard Star	G.
1928 Oct. 30	β Aris.	+1·00	+·05	+·29	+1·34
Nov. 15	β Aris.	+0·89	−·01	+·29	+1·17
1929 Aug. 26	α Lyra.	+1·04	+·02	·00	+1·06
Aug. 28	α Lyra.	+1·05	−·01	·00	+1·04
Sept. 26	α Andr.	+1·19	−·02	−·10	+1·07
Sept. 27	α Andr.	+1·27	−·02	−·10	+1·15
				Mean	+1·14

TABLE IV.—GRADIENTS AND COLOUR TEMPERATURES OF STARS.

No.	Star	R.A. 1925·0	Dec. 1925·0	Vis. Mag.	Spectral Type	Gradient G.	ϕ (G+1·16)	T
		h m s	° ′					°
1	α Andromedæ	0 4 30	+28 41	2·15	Aop	−0·10	1·06	16300
2	β Cassiopeiæ	0 5 10	58 44	2·42	F5	+0·71	1·87	7850
3	γ Pegasi	0 9 22	14 46	2·87	B2	−0·30	0·86	23900
4	γ Cassiopeiæ	0 52 10	60 19	2·25	Bop	+0·07	1·23	13100
5	δ Cassiopeiæ	1 20 54	59 51	2·80	A5	+0·25	1·41	10900
6	α Ursæ Minoris	1 34 14	+88 54	2·12	F8	+1·04	2·20	6600
7	ε Cassiopeiæ	1 48 59	63 18	3·44	B3	−0·22	0·94	19900
8	β Arietis	1 50 30	20 27	2·72	A5	+0·29	1·45	10600
9	β Trianguli	2 5 4	34 38	3·08	A5	+0·29	1·45	10600
10	β Persei	3 3 17	40 40	2·3–3·5	B8	−0·08	1·08	15900
11	ι Persei	3 3 38	+49 20	4·17	Go	+1·11	2·27	6400
12	δ Persei	3 37 35	47 33	3·10	B5	−0·16	1·00	17900
13	η Tauri	3 43 1	23 52	2·96	B5p	−0·02	1·14	14600
14	ζ Persei	3 49 25	31 40	2·91	B1	+0·35	1·51	10100
15	ε Persei	3 52 49	39 48	2·96	B1	−0·23	0·93	20500
16	α Camelopardi	4 46 35	+66 13	4·38	Bo	+0·18	1·34	11700
17	η Aurigæ	5 1 15	41 8	3·28	B3	−0·20	0·96	19400
18	α Aurigæ	5 11 9	45 55	0·21	Go	+1·49	2·65	5420
19	γ Orionis	5 21 6	6 17	1·70	B2	−0·24	0·92	20800
20	β Tauri	5 21 33	28 33	1·78	B8	−0·14	1·02	17500
21	β Aurigæ	5 54 2	+44 56	2·07	Aop	+0·06	1·22	13300
22	θ Aurigæ	5 54 36	37 13	2·71	Aop	−0·06	1·10	15400
23	χ^2 Orionis	5 59 28	20 8	4·71	B2p	+0·78	1·94	7550
24	γ Geminorum	6 33 23	16 28	1·93	Ao	+0·15	1·31	12000
25	β Canis Minoris	7 23 5	8 26	3·09	B8	−0·02	1·14	14600
26	α Geminorum	7 29 49	+32 3	1·58	Ao	+0·11	1·27	12600
27	ι Ursæ Majoris	8 54 5	48 20	3·12	A5	+0·50	1·66	9000
28	θ Ursæ Majoris	9 27 51	52 1	3·26	F8p	+1·12	2·28	6350
29	ε Leonis	9 41 36	24 7	3·12	Gop	+1·57	2·73	5260
30	α Leonis	10 4 23	12 20	1·34	B8	−0·08	1·08	15900
31	β Ursæ Majoris	10 57 20	+56 47	2·44	Ao	−0·02	1·14	14600
32	δ Leonis	11 10 7	20 56	2·58	A3	+0·29	1·45	10600
33	θ Leonis	11 10 18	15 50	3·41	Ao	+0·09	1·25	12900
34	β Leonis	11 45 14	14 59	2·23	A2	+0·17	1·33	11800
35	γ Ursæ Majoris	11 49 54	54 7	2·54	Ao	−0·05	1·11	15200
36	β Canum Ven.	12 30 11	+41 46	4·32	Go	+1·28	2·44	5920
37	ε Ursæ Majoris	12 50 44	56 22	1·68	Aop	−0·05	1·11	15200
38	α Canum Ven.	12 52 31	38 43	2·90	Aop	−0·06	1·10	15400
39	β Comæ	13 8 23	28 15	4·32	Go	+1·13	2·29	6300
40	ζ Ursæ Majoris	13 20 55	55 19	2·40	A2p	+0·16	1·32	11900
41	η Ursæ Majoris	13 44 35	+49 41	1·91	B3	−0·23	0·93	20500
42	η Boötis	13 51 7	18 46	2·80	Go	+1·09	2·25	6460
43	γ Boötis	14 29 4	38 38	3·00	Fo	+0·40	1·56	9700
44	γ Ursæ Minoris	15 20 50	72 6	3·14	A2	+0·19	1·35	11500
45	α Coronæ	15 31 31	26 58	2·31	Ao	+0·01	1·17	14200
46	ζ Herculis	16 38 27	+31 44	3·00	Go	+1·26	2·42	5960
47	α Ophiuchi	17 31 27	12 37	2·14	A5	+0·30	1·46	10500
48	α Lyræ	18 34 24	38 43	0·14	Ao	0·00	1·16	14300
49	γ Lyræ	18 56 8	32 35	3·30	Aop	−0·04	1·12	15100
50	ζ Aquilæ	19 1 58	13 45	3·02	Ao	+0·04	1·20	13600

No. 26. α Geminorum. Mean of components used.
No. 38. α Canum Ven. Brighter component used.

TABLE IV.—GRADIENTS AND COLOUR TEMPERATURES OF STARS—*continued.*

No.	Star	R.A. 1925·0	Dec. 1925·0	Vis. Mag.	Spectral Type	Gradient G.	ϕ (G+1·16)	T
		h m s	° ′					°
51	δ Cygni	19 42 38	+44 57	2·97	A0	−0·08	1·08	15900
52	α Aquilæ	19 47 7	8 40	0·89	A5	+0·42	1·58	9550
53	γ Cygni	20 19 32	40 1	2·32	F8p	+1·11	2·27	6400
54	β Delphini	20 34 2	14 20	3·72	F5	+0·85	2·01	7250
55	α Cygni	20 38 52	45 1	1·3	A2p	Var.		
56	Pi. 20^h332	20 43 30	+57 19	4·63	G0	+0·98	2·14	6780
57	α Cephei	21 16 47	62 16	2·60	A5	+0·43	1·59	9500
58	β Cephei	21 27 42	70 14	3·32	B1	−0·31	0·85	24300
59	9 Cephei	21 35 54	61 45	4·87	B2p	+0·74	1·90	7750
60	δ Cephei	22 26 23	58 2	3·6–4·1	F2–G2	Var.		
61	ζ Pegasi	22 37 43	+10 26	3·61	B8	−0·12	1·04	16900
62	α Pegasi	23 1 1	14 48	2·57	A0	−0·03	1·13	14800
63	υ Pegasi	23 21 38	22 59	4·57	G0	+1·14	2·30	6280

TABLE V

VALUES OF T, $\frac{c_2}{T}$ AND ϕ

$c_2 = 14{,}320$

$$\phi = \frac{c_2}{T} \Big/ \left(1 - e^{-\frac{2C_2}{T}}\right)$$

T	$\frac{c_2}{T}$	ϕ	$\phi - \frac{c_2}{T}$	T	$\frac{c_2}{T}$	ϕ	$\phi - \frac{c_2}{T}$
°				°			
2,000	7·16	7·16	0·00	12,000	1·19	1·31	0·12
2,500	5·73	5·73	0·00	12,500	1·15	1·28	0·13
3,000	4·77	4·77	0·00	13,000	1·10	1·24	0·14
3,500	4·09	4·09	0·00	13,500	1·06	1·21	0·15
4,000	3·58	3·58	0·00	14,000	1·02	1·18	0·16
4,500	3·18	3·18	0·00	14,500	0·99	1·15	0·16
5,000	2·86	2·87	0·01	15,000	0·96	1·13	0·17
5,500	2·60	2·62	0·02				
6,000	2·39	2·41	0·02	16,000	0·90	1·08	0·18
6,500	2·20	2·23	0·03	17,000	0·84	1·03	0·19
				18,000	0·80	1·00	0·20
7,000	2·04	2·08	0·04	19,000	0·75	0·96	0·21
7,500	1·91	1·95	0·04	20,000	0·72	0·94	0·22
8,000	1·79	1·84	0·05				
8,500	1·68	1·74	0·06	22,000	0·65	0·89	0·24
9,000	1·59	1·66	0·07	24,000	0·60	0·86	0·26
				26,000	0·55	0·82	0·27
9,500	1·51	1·59	0·08	28,000	0·51	0·80	0·29
10,000	1·43	1·52	0·09	30,000	0·48	0·78	0·30
10,500	1·36	1·46	0·10				
11,000	1·30	1·40	0·10				
11,500	1·25	1·36	0·11				
				∞	0·00	0·50	0·50

To facilitate computation a column is added giving values of $\phi - \frac{c_2}{T}$

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